Redfish Multidisciplinary Research Zonal Program (1995-1998): Final Report

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ABSTRACT

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This report provides under the form of extended abstracts the main results of the Redfish Multidisciplinary Research Program (1995-1999) which sought to examine aspects of the biology and fisheries of redfish to develop a better understanding of these species in order to insure long term economic viability and sustainability of the fishery. The program was divided into four main components: 1) Species identification and stock structure; 2) Improved stock assessment and management approaches; 3) Distribution in relation to environmental conditions; and 4) Recruitment studies. These objectives were established in a broad consultation with the redfish fishing industry and the results presented to them at a final workshop held in November 1999.

RÉSUMÉ

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Ce rapport présente les résultats du Programme de Recherche Multidisciplinaire sur le Sébaste (1995-1999) qui cherchait à examiner les aspects de la biologie et de la pêche au sébaste afin de mieux comprendre ces espèces dans le but de garantir la viabilité économique à long terme et un développement durable de la pêche. Le programme était divisé en quatre composantes principales: 1) Identification des espèces et structure des stocks; 2) Méthodes d'évaluation et de gestion améliorées; 3) Distribution en relation avec les conditions environnementales; et 4) Recrutement. Ces objectifs ont été établis suite à une vaste consultation auprès de l'industrie de la pêche au sébaste et les résultats leurs furent présentés lors d'un atelier en novembre 1999.

I. PROGRAM OVERVIEW AND INTRODUCTION

1. Introduction

1.1 Background

Redfish, also known as ocean perch or rosefish, belongs to a group of fish that are commercially exploited in both the Atlantic and Pacific Oceans. They occur on both sides of the Atlantic Ocean in cool waters (3° to 8°C) along the slopes of fishing banks and deep channels in depths of 100-700 m. In the west Atlantic, redfish range from Baffin Island in the north to waters off New Jersey in the south.

Three species of redfish are present in the Northwest Atlantic (*Sebastes mentella* Travin, 1951, *S. fasciatus* (Storer, 1854) and *S. marinus* L [also known as *S. norvegicus* (Ascanius, 1772) – see Robbins *et al.* (1991) for a summary of the issue], but the latter is relatively uncommon, except on Flemish Cap. These three species are similar and are nearly impossible to distinguish by cursory examination. They are not separated in the fishery, and they are managed together. There is however a geographic distributional cline for *S. mentella* and *S. fasciatus*, *S. mentella* being the only species in the far north (Davis Strait) and *S. fasciatus* being the only species in the south (Gulf of Maine). In the intermediate areas, both are found, *S. mentella* being generally distributed deeper than *S. fasciatus*. The exception to this general trend is the Gulf of St. Lawrence where *S. mentella* dominates.

With the decline of many groundfish stocks in the late 1980's, more sectors of industry have shown a renewed interest in redfish. This was particularly so in the Gulf of St. Lawrence (Unit 1), off Newfoundland's south coast (Unit 2) and in the Scotian Shelf area (Unit 3), although interest in other areas increased as well, for instance NAFO Division 3O where traditionally smaller redfish have been found (see Figure 1.1). However, some redfish stocks showed signs of rapid decline in the more traditional fishing areas, which lead to severe restrictions to fishing. In December 1994, the Minister of Fisheries and Oceans announced the closure of the redfish fishery in Unit 1 owing to the very low stock abundance and the lack of significant recruitment since the early 1980s. The fishery closure has remained in effect since then. The quota for Unit 2 redfish was gradually lowered from 25,000 tonnes to only 8,000 tonnes because of declining abundance. The redfish stock in Subarea 2 + Division 3K is at a low level, and the commercial fishery is closed.

At present, there are nine redfish management areas in the Northwest Atlantic: South Greenland (Division 1F), Labrador Shelf (Subarea 2 + Division 3K), Flemish Cap (Division 3M), Grand Banks (Divisions 3LN), Southern Grand Banks (Division 3O), Gulf of St. Lawrence (Unit 1 - Divisions 4RST, 3Pn4Vn [Jan. to May]), Laurentian Channel (Unit 2 - Divisions 3Ps4Vs4W_{fgi}, 3Pn4Vn [June to Dec.]), Scotian Shelf (Unit 3 - Divisions 4W_{degkl}X) and Gulf of Maine (Subarea 5) – (Figure 1.1). Except for Flemish Cap and

in the Gulf of Maine, Canada has prosecuted fisheries to varying degrees for redfish beginning in the late 1940s in these different management areas. The most commonly fished areas were Subarea 2 + Division 3K, as well as Units 1, 2 and 3.

Redfish are slow growing and long lived; specimens have been aged to at least 80 years. *Sebastes fasciatus* reaches a smaller size at age than *S. mentella* and growth is usually faster in southern areas than in northern areas; females also grow faster than males. On average, redfish take approximately 8 to 10 years to reach commercial size (25 cm or 10 inches).

Redfish are lecithotrophic (larvae feeding exclusively on energy stored in yolk) viviparous and fertilisation is internal. Mating occurs in the fall and females carry the developing young until the spring when they are released from April to July. In all areas examined, *Sebastes mentella* release their young a month earlier than *S. fasciatus*. Recruitment success in redfish is extremely variable, and significant year-classes have been observed from 5 to more than 12 year intervals.

Redfish biology differs considerably from the biology of other commercial species, yet assessment and management strategies employed have been the same. Because of these differences, and in light of the emerging problems in the redfish fisheries, a joint Industry-DFO workshop was held on June 1 and 2, 1995 to discuss the major issues pertaining to management of redfish stocks in the Northwest Atlantic. The workshop also sought to identify the important scientific questions related to management of these resources. As a result, the Redfish Multidisciplinary Research Program was conceived to examine aspects of the biology and fisheries of redfish to develop a better understanding of these species in order to insure the long term economic viability and sustainability of the fishery. Recognising, the unique characteristics of redfish, four broad categories of questions were identified at the workshop as being priority issues for research. They are:

1. Conservation measures: These include the conservation of immature fish, a review of management strategies and co-management.
2. Improved indicators of stock status: A series of recommendations was made to improve the tools currently in use to estimate the status of redfish resources such as the implementation of acoustic surveys, index and sentinel fisheries, the coverage of current surveys, the monitoring of technological changes in the fishery and work on improving the assessment techniques applied to redfish.
3. Distribution and stock identification: The specific questions asked covered species identification, the migrations and movements of redfish, stock definition and stock boundaries and the role of oceanographic conditions on distribution and migration.
4. Recruitment: The general issue of factors affecting success of recruitment of redfish (role of fish condition, larval and juvenile survival, etc.) was also raised, with a special emphasis on the disappearance of the 1988 year-class from Unit 1 (the 1988 year-class was very abundant in research survey at age 1 and 2, but disappeared thereafter from the survey (and the fishery) for reasons yet unexplained).

The issues identified by the stakeholders are broad and nearly all encompassing but the program that was planned through a series of workshop and discussions in 1995, addresses key issues amongst the priorities identified at the joint Industry / DFO workshop. The program was divided into four components, corresponding generally with the four broad priorities that emerged at the workshop, with a series of projects in each component. Below, follows a description of the program as it was originally conceived, and a series of extended abstracts describing the results of the various projects. During the course of the program, some projects were either modified, combined or abandoned as a result of new findings, and in the description below, the links between the original program and the final project are provided.

1.2 Species identification and stock structure

A clear understanding of the population structure of exploited species is a prerequisite to the proper management of the species. In the case of redfish, the situation is more complex because redfish stocks are actually comprised of several species. A clear understanding of species differentiation and distribution is thus essential for their management and for a proper understanding of their biology. The three species currently recognised in the Northwest Atlantic (*Sebastes mentella*, *S. fasciatus* and *S. marinus*) can be identified using several techniques. The number of soft rays in the anal fin (AFC), the extrinsic gas-bladder muscle (EGM) rib passage patterns and the malate dehydrogenase (MDH) electrophoretic mobility patterns are currently used to discriminate among the species. These methods have met with varying degrees of success (Payne and Ni 1982, McGlade *et al.* 1983, Rubec *et al.* 1991, Sévigny and de Lafontaine 1992), but they are often time consuming and are not routinely applied in field surveys. As a result, redfish is exploited and managed as one species.

In addition, the proper boundaries, if any, between specific or generic redfish "stocks" remains much in question. There has been a renewed interest in the question of stock definition and boundaries for redfish in areas of more intense exploitation, from the south coast of Newfoundland, the Gulf of St.-Lawrence, and the Scotian Shelf. Early stock definitions were based on bathymetric considerations and population differences. We know now that many of the "deep" channels are not barriers to redfish, and that many differences in life history traits such as growth, age and size at maturity, are in fact species related. Examinations of the distribution of commercial and research survey catches were also used at the beginning of the 1990's in an attempt to identify redfish stocks (Atkinson and Power 1991, D'Amours 1994, Anon. 1995), but so far no direct evidence exists that may help resolve the proper redfish stock structure in the Northwest Atlantic.

First, this component of the program sought to ascertain the correct identification of the species present in our area, to map their distribution and to provide tools to insure their correct "field" identification. Second, this component addressed the issue of stock structure and attempted to identify the various redfish stock in the Northwest Atlantic. Initially, four

interrelated projects were intended (genetic approach, otolith morphology, use of parasite as biological tags and active tagging), but the program quickly concentrated on the genetics, with a small contribution of parasite work. Results are described in chapter 2 : Species identification and stock structure on page 13.

1.3 Improved stock assessment and management approaches

There is a need to focus scientific attention on upgrading redfish stock assessment and management. A key issue to do so is to standardise data collection, survey design and assessment methodology in order to address issues on the broad geographical scale of redfish populations. The first one is the systematic, standardised, inter-regional collection of material which will allow a definitive description of the geographical distribution of Northwest Atlantic redfish by species, and for area-based definition of key biological parameters by species. The second issue is the standardisation of inter regional databases: there are data already on file, which can cast further light on stock separation and seasonal migration issues that need to be put in analysable form, and utilised, before any large investments are made in collection of new data of similar type. Thirdly, there are some important interactions between redfish and other species fisheries, particularly in Unit 3 where the redfish fishery is conducted in shallower water, on the whole, than to the northeast, which needed to be quantified. Three projects were initially planned in this component of the program, but only two were fully developed. Results are described in chapter 3 : Standardised Inter-Regional Redfish survey Sampling and Analysis of Growth and Maturity in Management Units 1,2,3 & NAFO Div 3O on page 49 and in chapter 4 : Retrospective Analysis of Redfish Catch Distribution: Inferences on redfish migrations through an analysis of commercial logbook information for Management Units 1-3 from 1988-1992 on page 57. The original project "Unit 3 fisheries interactions" was never fully implemented, but results were presented as part of the regular Unit 3 stock assessments.

1.4 Distribution in relation to environmental conditions.

Redfish distribution at the Unit 1/Unit 2 boundary appears to have changed in recent years, although it is unclear whether this change is the result of range contraction in response to a reduction in abundance, or a real shift in distribution. For instance, Morin and Bernier (1994) have hypothesised from catch distribution that Unit 1 redfish had extended their winter migration farther in the Laurentian Channel in the 1990s. Variability in the distribution and migration of redfish is of great concern to the fishery industry that must contend with fixed boundaries and cannot follow fish migrating across management unit boundaries. Environmental conditions have varied, sometimes quite considerably, in the area, and it had been postulated that the distribution of redfish would change in response to a changing environment.

Determination of environmental associations of redfish, particularly species-specific associations, will help to indicate the role of oceanographic conditions on the dis-

tribution, movements of redfish, and thereby assist in the interpretation of abundance indices, stock structure, and recruitment variability. For example, questions regarding the importance of oceanographic conditions in the decline of the 1988 year class in the Gulf, and more generally the influence of changes in oceanographic conditions on the representativeness of abundance indices, the overlapping or mixing of populations, and the commercial fishing pattern may be addressed in light of redfish environmental associations.

There are several useful approaches for estimating environmental effects on redfish distribution. For example, laboratory studies involving the monitoring of the behavioural response of captive redfish to environmental changes would provide a precise determination of redfish preferences under controlled conditions. Results of these studies are reported in chapter 5 : Temperature preference and tolerance in larval and adult redfish *S. fasciatus* and *S. mentella* on page 73. Some early results were obtained on the feeding habits of redfish that will become incorporated in an ecosystem model of the Gulf of Saint-Lawrence (section 10.3: Respective diets of *S. fasciatus* and *S. mentella.* on page 104). Chapter 6 : Acoustic properties of Atlantic redfish (*Sebastes* spp.), on page 79, assesses hydroacoustic properties of redfish and how hydroacoustics can be used to measure fine scale distribution in relation to environmental factors.

Finally, in order to explain the changes in the distribution of redfish during the 1990's, broad scale analyses of redfish distribution were attempted. In chapter 7 : Redfish Environmental Associations and Exposure Histories on page 85, statistical analyses of catch and environmental data have been used to assess the selection (or the non-random association) of redfish to available conditions in the environment which were used to conduct retrospective analyses of how climate change has influenced the distribution and migration of redfish within Atlantic Canada. In chapter 8 : Distribution changes of redfish in the Gulf of St. Lawrence based on research survey data on page 89, a more detailed examination of the distribution of redfish was undertaken at the boundary of Units 1 and 2, where changes have been most noticed by industry.

1.5 Recruitment studies

Success of recruitment in redfish is extremely variable, and significant year-classes are produced only at 5- to 12-year intervals (for instance 1946, 1956-1958, 1970, 1980 in Unit 1, Morin and Bernier 1994). Assuming then that larvae are released in similar quantities from year to year, mortality must occur sometimes between hatching and the time they reach age 1. Of the two species of beaked redfish, *S. mentella* releases its larvae about 3 to 4 weeks earlier than *S. fasciatus* in the Gulf (Gagné 1995, Sévigny *et al.* 2000) and on Flemish Cap (Templeman 1980). On the south coast of Newfoundland, *S. marinus* spawns earlier than beaked redfish thought to be predominantly *S. fasciatus* (Ni and Templeman 1985).

On Flemish Cap, larvae feed predominantly on immature stages of the copepod *Calanus finmarchicus*. Growth was faster, and metamorphosis occurred earlier in 1980 when there was a close match between hatching of redfish larvae and the spawning of *Calanus finmarchicus* than in 1981 when the hatching of *Calanus* occurred 7 weeks earlier (Anderson, 1994). He hypothesised that for good year-classes to occur, there had to be a close match. Larvae also feed predominantly on immature stages of the copepod *Calanus finmarchicus* in the Gulf of St. Lawrence (Runge and de Lafontaine, 1996). Other possible factors affecting survival during the pelagic phase are unknown.

On occasion in the Gulf of St. Lawrence, year-classes are present in very large numbers at age 1 (or 2) based on research survey data but they do not persist. The factors responsible for the disappearance of these small immature redfish are unknown. Migration is one possibility, although there are no data suggesting the 1988 year-class moved out of the Gulf (Anon. 1995). *Sebastes fasciatus* was the dominant species in the 1988 year-class whereas *S. mentella* dominated the 1980 year-class, which persisted in the Gulf. Nothing is known of the species composition of the previous year classes. Chapter 9 : Shrimp fishery bycatches of redfish and review of the possible causes of the disappearance of the 1988 year-class on page 95 examines some hypotheses about the disappearance of the 1988 year-class.

Despite important progress, recruitment studies in marine fish have not proven very successful at making useful predictions for fisheries management (Wooster and Bailey, 1989). However, most of recruitment studies deal with species showing much less extreme variability in successful recruitment than do redfish. The unpredictability of recruitment is a major issue for the management of redfish stocks and has significant impact on the fishing industry (for example, in the absence of successful recruitment since the early 1980's the fishery in the Gulf of St. Lawrence has been closed). Survival of redfish larvae appears to be dependent on the presence of early life stages of *Calanus finmarchicus* (Anderson, 1994; Runge and de Lafontaine 1996). While the timing of redfish spawning varies little from year to year, the timing and magnitude of *Calanus* production can vary significantly from year to year. Preliminary analyses of existing data from the gulf of St. Lawrence suggest that successful redfish year classes correspond to particular climatic conditions that may influence not only the physical conditions in which the larvae are produced but also the quantity and quality of their preferred prey. Within the recruitment portion of the program we examined aspects of the relationship between environmental variation and redfish survival that we hypothesise will affect the viability of the larvae. Results are reported in chapter 10 : Variability in reproductive characteristics and larvae production of redfish (*Sebastes fasciatus*) in the Gulf of St. Lawrence on page 99 and in chapter 11 : The Use of Endogenous and Exogenous Resources During the Early Development of Atlantic Redfish (*Sebastes* spp.) on page 119.

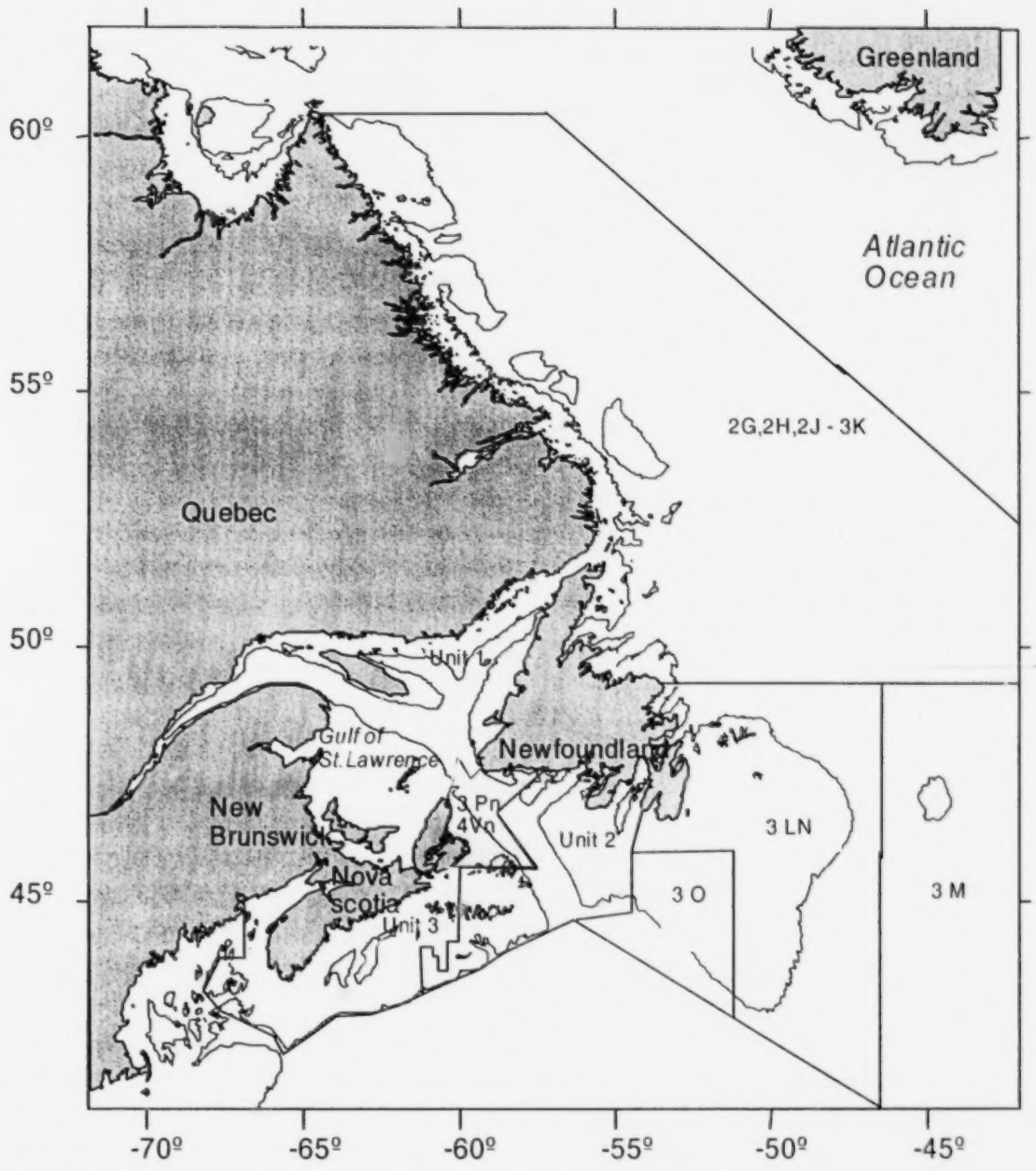

Figure 1.1. Map of the Northwest Atlantic showing the boundaries of NAFO Divisions and of Redfish management Units. The area in blue (NAFO subdivisions 3Pn and 4Vn) indicates the area of seasonal overlap between Units 1 and 2.

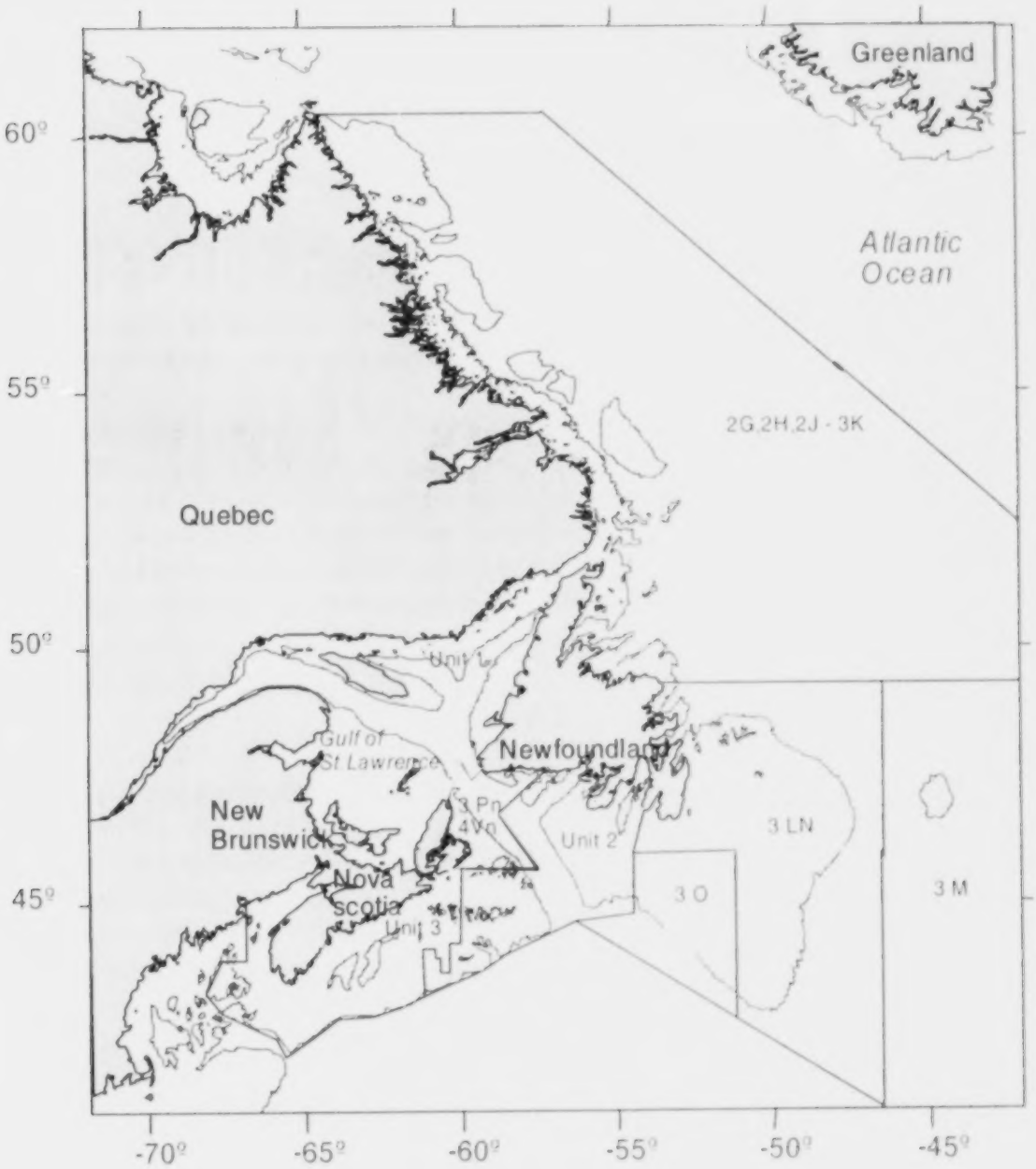

Figure 1.1. Map of the Northwest Atlantic showing the boundaries of NAFO Divisions and of Redfish management Units. The area in blue (NAFO subdivisions 3Pn and 4Vn) indicates the area of seasonal overlap between Units 1 and 2.

II. SPECIES IDENTIFICATION AND STOCK STRUCTURE

2. Species identification and stock structure

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The question of redfish species identification and the description of the stock structure were central in the Redfish Multidisciplinary Research Program 1995-1998. The difficulty of describing redfish stock structure and boundaries is compounded, by the fact that redfish stocks often comprise more than one species. Furthermore, the boundary between the species often needs to be clarified. Three species are currently recognised in the Northwest Atlantic, *Sebastes mentella* (Travin, 1951), *S. fasciatus* (Storer, 1854) and *S. marinus* (Ascanius, 1772) and a fourth one, *S. viviparus* is present in the Northeast At-

lantic. During the Program, genetic variability at microsatellite loci and for mtDNA was studied for all four species in order to provide a better understanding of the species boundaries and to provide the best possible tool for species identification. *Sebastes fasciatus* and *S. mentella* were the only two species for which stock structure was studied. Indeed, *S. marinus* was not frequently encountered during the sampling program and therefore it was not considered in stock identification studies.

The general objectives of this component of the program can be summarised as follow:

1. Seeks to correctly identify the species present in the Northwest Atlantic and to provide tools to insure their correct "field" identification.
2. Attempt to develop tools to obtain direct information on redfish migrations and movements.

During the program, the number of soft rays in the anal fin (AFC), the extrinsic gasbladder muscle passage (EGM) and the genotype at the *MDH-A** locus were systematically recorded (Figure 2.1). These three characteristics are usually used to discriminate *S. mentella* from *S. fasciatus* in the Northwest Atlantic, although, until the program, they have never been extensively compared. The concomitant use of the three criteria gave valuable information on species distribution and interrelation. These results are presented in section 2.1.

Although the usual criteria (MDH, EGM, AFC) can provide useful information regarding species identification and distribution, MDH is the only one that can be used for all stages of the life cycle (e.g. Sévigny and de Lafontaine 1992; Sévigny *et al.* 2000). Furthermore, none of these criteria provide information on stock structure i.e. within species structuring. Therefore, this component of the Program dealt with the development of new approaches and new tools that would be appropriate to detect differences at the level of species and stocks.

The four interrelated projects (or groups of projects) included in this component of the program and addressing either the question of species identification or of stock structure or both are presented in sections 2.2 to 2.5 and cover respectively the:

- Genetic variation in the Gulf of St. Lawrence and the Northwest Atlantic;
- Species identification based on shape analyses;
- Use of parasite as biological tags; and
- Experimental tagging.

2.1 AFC, EGM, and MDH, the three usual characteristics for species identification

So far three characteristics have been commonly used to discriminate *S. mentella* from *S. fasciatus* in the Northwest Atlantic (Figure 2.1). They are (i) the number of soft

rays in the anal fin (AFC) (≥8 for *S. mentella*, ≤7 for *S. fasciatus*) (Ni, 1982), (ii) the extrinsic gasbladder muscle passage (EGM) (between ribs 2 and 3 for *S. mentella*, between ribs 3 and 4 or more for *S. fasciatus*) (Ni, 1981), (iii) the genotype at the malate dehydrogenase locus (*MDH-A**). The *MDH-A** locus is polymorphic with two codominant alleles, *MDH-A*1* and *MDH-A*2*, that combine to form three possible genotypes. *MDH-A*11* characterise *S. mentella*, while *MDH-A*22* is associated with *S. fasciatus* (Payne and Ni 1982, McGlade *et al.* 1983). The heterozygous genotype, *MDH-A*12* cannot be assigned unambiguously to one species and is assumed to be of hybrid origin.

The value of AFC, EGM and MDH for redfish species discrimination has been somewhat controversial. However, these criteria have seldom been compared or even used concurrently in sampling programs. This is mainly due to difference in the methodology used to carry out species identification. The advantage of using these markers is that, except for MDH, they can be used on board research vessels and applied in large-scale sampling program. They are inexpensive to use. Although time consuming, during the Program, the sampling methodology was standardised and the three criteria were recorded systematically on all the samples collected in the three Atlantic DFO regions involved in redfish management: Quebec, Maritimes and Newfoundland. Such sampling strategy allowed us to determine the relevance of these criteria for redfish species identification in various areas of the redfish distribution. The congruence of these criteria and their reliability as to identify redfish species rapidly was also assessed.

The samples collected and classified with the usual criteria served as the basis for the development and application to the redfish problematic of new tools (e.g. microsatellite DNA, geometric morphometrics). Since the studies of the various components of the program were all initiated simultaneously and at a time when the new molecular markers for species identification were not yet available, one or all of the usual criteria were used in those studies in which species identification was needed (e.g. identification of redfish larvae). The information on species distribution and interaction that could be obtained from the systematic use of the three criteria is presented below.

2.1.1 Species identification and distribution based on usual criteria

The three criteria (MDH, EGM and AFC) were used concurrently in Unit 1 and 2 in 1994, one year before the beginning of the Program. From 1994 to 1998, a total of 7635 redfish was sampled and identified using these criteria in all redfish NAFO divisions. These samples cover most of the redfish geographic distribution in the Northwest Atlantic i.e. from the Gulf of Maine to the Labrador Sea and the Gulf of St. Lawrence (Figure 2.2; Table 2.1) and they also comprise different size/age classes (Table 2.2).

A general picture emerges from the concurrent study of the geographic distribution of the MDH, EGM and AFC characteristics (Figure 2.3 Figure 2.4 and Figure 2.5). Indeed, these three criteria indicate that, in the Northwest Atlantic, the distribution of the two most important redfish species differs significantly. This patterns is well illustrated by the distri-

bution of the variability at the *MDH-A** locus. The distribution of this criterion shows that *S. fasciatus* is almost the only species represented in the southern part of the redfish distribution, the Gulf of Maine and Unit 3 (Scotian Shelf). In these two management Units, the frequencies of the allele *MDH-A*2*, which is characteristic of *S. fasciatus*, are equal to 1 and 0.97 respectively (Table 2.2). In these two divisions, only 18 individuals out of 712 show the genotype corresponding to *S. mentella*. In the northern part of the Northwest Atlantic redfish distribution (Subarea 2 + Div 3K), most individuals had the genotype corresponding to *S. mentella*. In this part of the redfish species distribution, *S. mentella* is the most important species although *S. fasciatus* was also observed in small proportion (Figure 2.3; Table 2.2). The frequencies of the different genotypes at the *MDH-A** locus indicate that both species are well represented in the NAFO divisions 3M, 3N, 3LN, 3O, Units 1 and 2 (Table 2.3).

The change in the species distribution across the NAFO divisions created a north-south cline in allelic frequency with complete allele substitution at the *MDH-A** locus. Indeed, allele *MDH-A*1* characteristic of *S. mentella* is the most frequent in the northern part of the species distribution while the frequency of allele *MDH-A*2* characteristic of *S. faciatus* is very high in the southern part. The presence of the two redfish species in most NAFO divisions translate not surprisingly in important deviations from Hardy-Weinberg expectations; all of them being associated with deficits in heterozygotes (Table 2.3). Such result is expected when two or more sampled groups, in this case *S. fasciatus* and *S. mentella*, are not interbreeding freely.

The redfish species distribution deduced from the data on MDH variability generally applies to the other two criteria; the EGM and AFC (Figure 2.4 and Figure 2.5). Indeed, EGM and AFC typical of *S. fasciatus* are largely dominating the southern part of the distribution while the northern part is dominated by the criteria typical of *S. mentella*. It can be concluded that the distribution of these two species is characterised by two areas of allopatry, located in the north (*S. mentella*) and in the south (*S. fasciatus*). These areas of allopatry are separated by a large zone of sympatry where both species are represented (Figure 2.6).

The level of congruence between AFC, EGM and MDH varies across the Northwest Atlantic and is high in allopatric zones. Indeed, in the Labrador Sea, where *S. mentella* represents more than 85% of the specimens the overall congruence reaches 93% whereas in Unit 3 and Gulf of Maine, where *S. fasciatus* is almost the only species present, the congruence is close to 99% (Figure 2.7). Thus, the three criteria are quite equivalent to discriminate redfish species in allopatry. The situation is different in the area of sympatry where the level of congruence is generally lower (Figure 2.7). However, the level of congruence is not homogenous across the area of sympatry as it follows a gradient with values diminishing from Divisions 3LNO (85%) to Unit 2 (68%) and finally to Unit 1 including the Saguenay Fjord (56%) (Figure 2.7). Overall, the low level of congruence observed between the three criteria in Unit 1 and Unit 2 underlines the limit to the use of a single crite-

rion for species identification in these Units, and reinforces the need of a multivariate approach. Furthermore, the low level of congruence observed in these two management Units is the most likely cause of the confusion that has taken place over the years around the use of redfish classification criteria.

In this context, an interesting observation can be made from the distribution of the genotypes at the *MDH-A** locus and EGM patterns. For these two criteria, there are intermediate types; the heterozygous individuals *MDH-A*12* and those individuals for which the extrinsic gasbladder musculature is bifurcated and passes between ribs 2 - 3 and 3 - 4 (individuals with these intermediate characteristics are called "doubtful"). The distribution of redfish individuals with intermediate characteristics is largely restricted to Units 1 and 2 (Figure 2.3 and Figure 2.4) and to a much lesser extent in NAFO divisions 3LN, 3O and 3M. They were not observed in the Gulf of Maine and in Unit 3 and the frequency of these individuals was very low in NAFO division 2+3K. It is worth mentioning however that sample size in 3K and 3M was small. The concentration of individuals with intermediate characteristics mainly in Units 1 and 2 suggests that these two Units may be considered as a subdivision of the sympatric area. Units 1 and 2 correspond to the area where introgressive hybridisation is taking place and this process is likely responsible for the particularities of the usual criteria that are observed in these two Units (see Sections 2.1.2 and 2.2).

2.1.2 Evidence of introgressive hybridisation based on usual criteria

Introgressive hybridisation between *S. fasciatus* and *S. mentella* has been suggested as the most likely explanation for the presence of individual redfish with intermediate or with non congruent characteristics mainly in the Gulf of St. Lawrence and in the Laurentian Channel (Rubec *et al.* 1991, Desrosiers *et al.* 1999, Roques *et al.* 2001; see Section 2.2.1.3). Although the mode of inheritance of the EGM patterns is not known, MDH electrophoretic patterns are transmitted as a Mendelian character. It can be hypothesised that, in the process of introgressive hybridisation, fertile hybrids are produced between *S. fasciatus* and *S. mentella* and that these hybrids backcross with one of the parental species. The overall result of the process is the incorporation of genes of one species into the gene pool of the other. As it will be discussed later, this process plays a very important role in population structuring in the Northwest Atlantic (Roques *et al.* 2001; section 2.1.1). The reasons why this process is almost restricted to Units 1 and 2 are not known. However, the fact that the distribution of the introgressed individuals appears to be limited to the Gulf of St. Lawrence and Laurentian Channel system suggests a limited dispersion capacity of these individuals. It also suggests the existence of a strong interaction between the two NAFO management Units. The interaction between the two Units will have to be studied further to understand the nature of this interaction, the importance of migration and larval dispersion, and the impact on the recruitment in both Units

2.2 Genetic variation in redfish (*Sebastes* sp.) in the Gulf of St. Lawrence and the Northwest Atlantic

2.2.1 Redfish species identification studies based on ribosomal, mitochondrial or microsatellite DNA polymorphisms

Different studies involving various molecular approaches were carried out in order to assess the level of differentiation among the recognised redfish species in the North Atlantic. Some of these considered only the two most important redfish species (*S. fasciatus* and *S. mentella*) while others considered all four of them. The results of most of these studies have been published. They are summarised in this section and the reference to the published version is given.

2.2.1.1 Ribosomal DNA polymorphism of *S. fasciatus* and *S. mentella* in the Gulf of St. Lawrence

B. Desrosiers, J.-M. Sévigny and J.-P. Chanut

This restriction fragment length polymorphism study (RFLP) of ribosomal DNA (rDNA) in the redfish *S. fasciatus* and *S. mentella* from the Gulf of St. Lawrence (Desrosiers *et al.* 1999) was undertaken before the beginning of the Redfish Multidisciplinary Research Program and was completed during the Program. The study of the structure and polymorphism of the ribosomal DNA multigene family is very relevant to the redfish species identification question. Indeed, this gene family has been extensively used in the description of the phylogenetic relationships among closely related species such as salmonids (e.g. Phillips *et al.* 1992) as well as for the identification of sibling species and their hybrids (e.g. Ghosh *et al.* 1991). The objectives were thus to determine if this gene family would allow the discrimination of *S. fasciatus* and of *S. mentella* in the Gulf of St. Lawrence.

For this study, more than 100 individual redfish were collected in the Gulf of St. Lawrence, mainly in the Esquiman Channel. The position of several restriction sites was described in the two species (Figure 2.9). The double digestion of rDNA with the restriction enzymes *Eco*RI and *Sca*I with subsequent hybridisation with a 28S probe revealed the presence of three patterns of fragments (Figure 2.10). Two fragment groups seemed to characterise *S. mentella* and *S. fasciatus*. However both fragment groups were present in several specimens suggesting a hybrid origin for these redfish. Furthermore the comparison of genetic variations at the *MDH-A** locus and of the number of soft rays in the anal fin (AFC) among the three rDNA groups suggested that introgression (i.e. the incorporation of genes from one species into the gene pool of another species) has occurred in the Gulf of St. Lawrence between *S. fasciatus* and *S. mentella*.

2.2.1.2 MITOCHONDRIAL DNA POLYMORPHISM IN REDFISH

M. Black and J.-M. Sévigny

The mitochondrial genome consists of a small molecule (mtDNA) that has been commonly used for species as well as for stock discrimination in a large number of species (Avise 1994). It is maternally inherited and its rate of evolution is fast. Therefore, as it was the case for rDNA gene family, the study of variability of this genetic marker was expected to provide useful information not only on species and stock discrimination aspect of the redfish problematic but also on the dynamic of introgressive hybridisation that is taking place between the two species.

The sequence of two redfish mitochondrial DNA fragments was determined. The first fragment, which is approximately 1100bp in length, encodes the complete ND4L gene and the initial half of ND4 gene. The second fragment is approximately 410bp and represents the most variable segment of the mitochondrial control region (or 'D-loop'). Sequence data were collected from 2-3 individuals of each redfish species and morphs (e.g. oceanic redfish) to allow estimates of divergence within and among species. Levels of both intraspecific and interspecific variation were quite low and variation, which would allow the development of species mtDNA genetic markers, could not be detected. An independent investigation of the mitochondrial 16S rRNA (Sundt and Johansen 1998) as confirmed the low level of variation of the mitochondrial DNA within this genus and may indicate recent evolutionary divergence between species. This project was not continued.

2.2.1.3 DEVELOPMENT AND APPLICATION OF MICROSATELLITE DNA MARKERS FOR REDFISH SPECIES IDENTIFICATION.

S. Roques, J-M Sévigny and L. Bernatchez

During the first year of the program, eight microsatellite DNA markers were developed for redfish studies (Roques *et al.* 1999a). These markers were then used to test the hypothesis that microsatellites can diagnostically discriminate individual redfish and provide a quantification of the amount of divergence among the four recognised species (*S. fasciatus*, *S. mentella*, *S. marinus* and *S. viviparus*) present in the North Atlantic (Roques *et al.* 1999b). For this test, two samples of each of the four species were collected in the North Atlantic. *Sebastes fasciatus* samples were collected in the Gulf of Maine and on the Scotian Shelf while *S. mentella* samples were collected on the shelf break off Nova Scotia and in the Laurentian Channel. All samples of *S. marinus* and of *S. viviparus* came from Norwegian waters. All the individuals were first classified using meristic (AFC), morphological (EGM) and genetic (MDH) characteristics usually used for redfish identification.

Results of this study reveal highly significant difference ($P \leq 0.001$) in allelic frequencies at all loci between the four studied species. In fact, only 20% of the alleles detected were shared among them. The genetic differentiation among species was also illus-

trated when multilocus microsatellite genotypes were used to describe the relationship among individual redfish. Indeed, a neighbour-joining tree (Figure 2.13) built from the matrix of shared allele distances comprised four clusters that correspond completely to the redfish species (*S. fasciatus*, *S. mentella*, *S. marinus* and *S. viviparus*). In this study only six individual specimens out of 260 (two *S. marinus* and four *S. mentella*) were assigned to the wrong species. The percentages of assignment success observed among the four species were very high ranging between 87-100% when all loci were used. This study reveals the usefulness of microsatellite multilocus genotype analyses to discriminate individuals of the redfish taxa present in the North Atlantic. This study also supports the hypothesis of Barsukov (1972) that *S. fasciatus* and *S. viviparus* are more closely related to each other than they are to the other species of the taxa and that *S. marinus* has a basal relationship relative to other redfish from the North Atlantic.

Despite the power of molecular tools to discriminate redfish species, the question of redfish species definition in the Northwest Atlantic is complicated by the fact that *S. fasciatus* and *S. mentella* hybridise and introgress in some part of the area of sympatry more specifically in the Gulf of St. Lawrence and the Laurentian Channel (Units 1 and 2). Therefore, the dynamics of introgression between *S. fasciatus* and *S. mentella* was examined in a detailed study using microsatellite DNA markers (Roques *et al.* 2001).

In this study, 17 samples, six for *S. fasciatus* and 11 for *S. mentella*, were collected in the allopatric and sympatric zones (Figure 2.7 and Figure 2.8). Comparison of the genetic characteristics of the samples reveals that introgression has very important effects on genetic diversity and population structure of both species. One of the effects was a modification of genetic variability of both species. Indeed, for *S. fasciatus*, heterozygosity increased from 0.757 in allopatric samples to 0.832 in the area of introgression. For *S. mentella* the number of alleles decreased in the area of introgression (149 compare to 160). Introgression, since it involves exchange of genes from one species to the other, also tends to decrease divergence between *S. fasciatus* and *S. mentella*. This is illustrated in the results of a factorial correspondence analysis based on 569 individuals. This analysis showed that the sympatric samples positioned between the allopatric samples and created a continuum between the two species groups (Figure 2.14). For a given species, sympatric individuals were genetically closer to the individuals of the other species, than were allopatric individuals. Furthermore, the sympatric samples comprised individuals possessing alleles of both *S. fasciatus* and *S. mentella*, rather than an admixture of pure individuals from the two taxa. This study also revealed that introgression, while bi-directional, was asymmetrically more important towards *S. mentella* indicating that it did not affect both species in the same way. The reasons for such a pattern are not well understood and a combination of selective and ecological (e.g. abundance, reproductive periods) factors may be invoked to explain that pattern (see Roques *et al.* 2001 for a detailed discussion).

It is also worth mentioning that the introgression, although important (average rate of introgression = 15%) is geographically circumscribed to Units 1 and 2 where the two

reproductively isolated introgressed groups persist. Furthermore, since introgression is geographically limited, the genetic integrity of both species outside the defined zone of introgression is maintained. This maintenance takes place despite high potential for gene flow through larval dispersion. The results of this study highlighted the predominant role of introgressive hybridisation in shaping the extent of genetic diversity within species, in the evolution of interspecific differences and, as will be seen in the next section, in the population structuring of both *S. fasciatus* and *S. mentella*.

2.2.2 Redfish stock discrimination studies based on microsatellite DNA markers.

S. Roques, J-M. Sévigny and L. Bernatchez

In contrast to the high assignment success observed among the four redfish species, the microsatellite markers were not as powerful to discriminate redfish at the population level (Roques *et al.*, 1999b). Moreover, the assignment success varied dramatically according to the threshold of stringency selected for the assignment procedure. This suggested that differentiation among populations within species (i.e. stock structure) is low in redfish, an observation that is in agreement with the weak genetic structuring usually reported for other marine organisms. It also illustrated the lack of power of the set of loci used for population assignment within redfish species. Testing and application of additional microsatellite markers (e.g. Miller *et al.* 2000) may therefore be required to improve the resolution of redfish stock structure.

So far the results of the microsatellites analyses have revealed, for *S. fasciatus*, the existence of significant differences in allelic frequencies between samples collected in the Gulf of Maine (FAA1) and in Unit 3 (FAA2) ($\theta = 0.0132$) and there was no difference among the four sampling sites of the Gulf of St. Lawrence and of the Laurentian Channel FAS1, 2, 3, 4 (averaged $\theta = 0.0006$). The θ values, however, were neither significant among the samples collected in the area of sympatry or between FAA1 and FAA2. For this species, three population Units appear to exist: 1) Units 1 and 2; 2) Unit 3; 3) Gulf of Maine. The homogeneity observed between samples from Units 1and and 2 is in agreement with the studies showing that introgressive hybridisation is taking place in these two areas. The differentiation of these *S. fasciatus* from those of Unit 3 is most likely the result of introgressive hybridisation with *S. mentella* that is taking place in the Gulf of St. Lawrence and in the Laurentian Channel. Indeed, incorporation of genes from *S. mentella* into the genome of *S. fasciatus* from these areas of sympatry will increase the genetic difference between *S. fasciatus* from the area where introgression occurs with those from the allopatric area (i.e. Unit 3). The difference observed between *S. fasciatus* from the Gulf of Maine and those from Unit 3 is more difficult to explain and additional sampling and analyses will be needed to confirm the results of the present study. It can be hypothesised that a combination of life history characteristics (e.g. less migratory behaviour) and environmental factors (e.g. circulation patterns) may be involved in the differentiation patterns observed.

The stock structure appears to be complex in *S. mentella* for which samples were available across the North Atlantic (Figure 2.10) (Roques *et al.* 2002). For this species, the results reveal the existence of a week pattern of genetic structure and suggest the occurrence of three main population Units: 1) the western group comprises redfish from Gulf of St. Lawrence and the Laurentian Channel (Units 1 and 2); 2) the panoceanic group comprises most samples across the Atlantic, from the Grand Banks and Labrador Sea to the Faeroe Islands i.e. 5000 km; 3) the eastern group comprises Norway and Barents Sea samples (Figure 2.13). At this scale, genetic breaks were found at both extremes of the range of *S. mentella*, with clear differentiation of samples from the western group from all other groups in both allelic frequencies and in other indices of genetic differentiation (mean $\theta = 0.0127$). Significant differences were also found between Norway and all the other groups ($\theta = 0.0239$). These differences between the groups may be attributed to oceanographic settings and/or vicariance (discontinuous biogeographical distribution of organisms that previously inhabited a continuous range) events in the eastern regions (Norway and Barents Sea) and to the existence of an introgressive hybridisation zone in the Gulf of St. Lawrence and the Laurentian Channel (Units 1 and 2). Indeed, the process described earlier for *S. fasciatus* also applies to *S. mentella*. The incorporation of *S. fasciatus* genes into the genome of *S. mentella* in the Gulf of St. Lawrence and the Laurentian Channel will increase the genetic difference with *S. mentella* from areas where this process does not take place. The weak structuring observed in the panoceanic region could be an indication of extensive larval dispersion across the area. The general circulation patterns in the North Atlantic is consistent with this hypothesis. Furthermore, such broad patterns suggest that larval dispersion from the panoceanic population Unit may influence redfish recruitment in the Northwest Atlantic especially those of the Labrador Sea and Grand Banks stocks. Further studies with more detailed sampling will be needed to assess the importance of this phenomenon given the development of a new fishery in west Greenland (NAFO 1F).

In addition to the broad scale structuring described above, genetic heterogeneity although modest was also detected within the three *S. mentella* main groups. For example, significant differences were observed between the Newfoundland sample NFD4, and the other samples from the same region, NFD1-NFD3. NFD3 was also significantly different from NFD1 and NFD5. The differentiation of those two samples from the others was attributed to variable levels of introgression observed in these regions. Additional sampling will be needed in this area given the importance of the biological relevance of the boundary between Units 1 and 2. Differences in allelic frequencies were also observed in the Panoceanic group; samples from Iceland and west Greenland being different from other samples.

2.3 Redfish species identification based on shape

2.3.1 Redfish species identification based on otolith shape

D.B. Atkinson

Otolith shape has been used to differentiate between different species (L'Abée-Lund 1988) and stocks (Campana and Casselman 1992, 1993, Castonguay *et al.* 1991) of fish. Successful application of this approach to the redfish species question would allow for detailed species separation from research and commercial data going back about 20-30 years.

The hypothesis to be tested is "The two species of redfish, *S. mentella* and *S. fasciatus* can be separated based on otolith shape". If the hypothesis is accepted, the project would be expanded so as to estimate species composition historically based on both commercial and research otolith records. Results may be compared to molecular biology results obtained on the same otolith when these molecular markers are available.

Preliminary results reveal that the variability in otolith shape was too high to allow the application of this approach to the redfish species identification question. This study was not continued.

2.3.2 Geometric morphometric approach for redfish species discrimination

A. Valentin, J.-M. Sévigny and J.-P. Chanut

The objective of this study is to determine if body shape can be used to differentiate between *S. fasciatus*, *S. mentella* and their putative hybrids in the Gulf of St. Lawrence using geometric morphometrics. The approach consists, through a procrustes procedure coupled with multivariate statistics, in defining body shape differences between the three genotypes at the *MDH-A** locus.

The core of geometric morphometrics consists of recently developed techniques inspired by the deformation grids proposed by D'Arcy Thompson (1917). These comprise different methods such as Euclidean distance matrix analysis, finite element scaling analysis, shape or Bookstein coordinates, thin plate spline transformations and superimposition or procrustes methods (Rohlf and Marcus, 1993 and references therein; Corti, 1993; David and Laurin, 1997). These techniques are more effective than traditional morphometrics in localising where shape differences occurs (Rohlf and Marcus, 1993). In geometric morphometrics, landmarks are used as input data, encoded as two-dimensional (x, y) or even three-dimensional (x, y, z) coordinates. These coordinates are transformed to shape variables that are invariant to scale, location and orientation. The relative spatial arrangement of landmarks is conserved throughout the analysis, a characteristic that allows for an easily interpretable visualisation of morphological variability in the original specimens' space.

Fish were collected in April 1997 with a bottom-trawl net in the Gulf of St. Lawrence. Trawling depth varied from 150 m to 500 m to ensure that both species were caught. The sampling sites covered two geographic areas: (1) East of Anticosti Island to Cabot Strait, and (2) North of Gaspé Peninsula to South of Anticosti Island. All specimens were first classified according to the variability at the *MDH-A** locus, a diagnostic criterion for the two species in allopatry (see previous section). Eighteen landmarks defining the outline of the body were selected as morphometric data (Figure 2.14). The (*x*, *y*) coordinates of landmarks were transformed to shape variables through a procrustes approach using APS software (Penin, 1999). The shape variables were introduced in a discriminant function analysis to test the shape differences between the three genotypes that means between *S. mentella*, *S. fasciatus*, and their putative hybrids.

The discriminant function analysis significantly discriminates ($F = 6.371$; $P < 0.0001$) the three groups (Figure 2.16). The body shape of hybrids is close to that of *S. mentella*. Body shape differences between *S. fasciatus* and *S. mentella* are highly significant ($F = 11.64$; $P < 0.0001$). *Sebastes mentella* appears to be more fusiform than *S. fasciatus*, a characteristic that may reflect the more pelagic behaviour of *S. mentella* (Figure 2.16a). The variables that best discriminate between the two species are L5, L6 and, to a lesser extent, Y13 (Figure 2.16a, b). They affect the length between the anterior extremity of the body and the anterior insertion of the dorsal fin (LD), as well as the length between the anterior insertion of the dorsal and anal fins (AD). Although data were collected in different areas of the Gulf, sample size did not allow for intra and inter-specific morphological comparisons between geographic areas. However, LD and AD have been identified as being among the best discriminators between *S. mentella* and *S. fasciatus* from the Flemish Cap and Newfoundland's Grand Banks (Saborido-Rey, 1994). Thus, this previous study and our results suggest that *S. mentella* and *S. fasciatus* are characterised by a specific body shape that is maintained in different redfish populations throughout its range. Therefore, body shape would be a promising approach for species as well as for stock discrimination.

2.4 Use of parasites in stock identification of the deepwater redfish (*Sebastes mentella*) in the Northwest Atlantic

D.J. Marcogliese, R. Arthur and E. Albert

Parasites were examined from deepwater redfish (*Sebastes mentella*) collected from five areas in the Northwest Atlantic Ocean to assist in determination of the stock structure of their populations for fisheries management in Atlantic Canada. Fish were collected from Flemish Pass (3M), off Labrador (2J), in the Laurentian Channel (4Vn in August; 3Ps in January = Unit 2), in Cabot Strait (3Pn = Unit 2) and from the Gulf of St. Lawrence (4T = Unit 1) between August 1996 and January 1997 (Figure 2.17)

A total of sixteen parasite taxa were found, including one myxozoan, eight digeneans, two cestodes, three nematodes, and two copepods. Of these, only four proved useful to discriminate among stocks of *S. mentella*. These are the anisakid nematodes *Anisakis simplex* and *Hysterothylacium aduncum*, and the copepod *Sphyrion lumpi*. *Anisakis simplex* was common at almost all sites, being particularly abundant off Labrador, on the Flemish Cap, and in the Gulf of St. Lawrence.

The most prevalent and abundant parasite encountered was *H. aduncum* in redfish from the Flemish Cap. The copepod *S. lumpi* was most prevalent in the Gulf of St. Lawrence and the Laurentian Channel. The prevalence (% of fish infected), mean intensity (mean number of parasites in infected fish) and intensity range of these parasites are shown in Table 2.4.

Multiple non-parametric analyses demonstrated that distinct stocks of redfish occurred off Labrador and on the Flemish Cap, which agrees with earlier studies (Bourgeois and Ni, 1984; Templeman and Squires, 1960). Analyses also suggested that fish could be separated from the Gulf of St. Lawrence (summer), and the Cabot Strait (summer) or Laurentian Channel (summer or winter) (Table 2.5).

Parasitological data suggest that redfish from Unit 1 and Unit 2 may belong to separate stocks. These data should be used in conjunction with other methods of stock discrimination to verify the results.

2.5 Experimental tagging of redfish

D. Gascon

Redfish are not amenable to traditional tagging techniques as they hardly ever survive decompression of more than few tens of meters. The only possible avenue is thus to tag fish directly at depth, using detachable hooks or breakaway tags (Horn 1988, Love *et al*, 1994). The object of this proposal was to test the applicability of this technique for Atlantic redfish in order to implement a full-fledged tagging program if the test proves successful.

This project could not be carried because of budget restrictions.

Table 2.1. Number of individuals collected from 1994 to 1998 in each NAFO redfish management division and for which data on Numbers of soft rays at the anal fin (AFC), Extrinsic gasbladder muscle rib passage pattern (EGM) and malate dehydrogenase (MDH) genotypes are available. Note: the Saguenay Fjord is part of Unit 1. Sp: spring (March, April, May); Su: summer (June, July, August); F: fall (September, October, November); W: winter (December, January, February).

Region	1994				1995				1996				1997				1998				Total
	Sp	Su	F	W	Sp	Su	F	W	Sp	Su	F	W	Sp	Su	F	W	Sp	Su	F	W	
Div. 3K											28					41		84	630		783
3LN														102	50	40					192
3M											23										23
3O						61				128			49	46	80						364
Unit 1		292		310		352	36			618				264					55		1927
Unit 2	685					877				102	110			720					80		3565
Unit 3						376				39	208										623
Saguenay												69									69
Gulf of Maine											89										89
Total	685	292		310		166	36			141	205	140	69	49	113	130	81	84	765		7635

Table 2.2. Size distribution of the samples analysed. Sample size sometimes differs from those from Table 2.1 due to missing data on size. *N*: sample size; Min: minimum size values; Max: maximum size value; C.V. coefficient of variation.

Region	*N*	Min.	Max.	Mean	C.V.
2G-3K	*782*	93	505	222.8	0.26
3M	*23*	90	380	198.7	0.45
3LN	*186*	146	440	261.5	0.24
3O	*363*	80	430	256.3	0.29
Saguenay	*69*	220	330	265.3	0.08
Unit 1	*1927*	7	515	235.7	0.50
Unit 2	*3565*	60	530	288.0	0.28
Unit 3	*623*	80	460	252.4	0.31
G. Maine	*89*	150	280	198.5	0.14
All regions	7627	7	530	261.5	0.35

Table 2.3. Observed (Obs.) and expected (Exp.) number of individuals of each of the three genotypes at the *MDH-A** locus and allelic frequencies in samples collected between 1994 and 1998 in each NAFO division. *N* = sample size.

NAFO Divisions	*N*	Genotype						Allelic Frequency	
		A1A1		A1A2		A2A2			
		Obs.	*Exp.*	*Obs.*	*Exp.*	*Obs.*	*Exp.*	**A1*	**A2*
Subarea 2 + Div. 3K	783	671	579	5	189	107	15	0.86	0.14
3M	23	16	12	1	9	6	2	0.72	0.28
3LN	192	112	67	1	93	79	32	0.59	0.41
3O	364	77	18	3	125	284	221	0.22	0.78
Unit 1	1927	826	482	256	963	845	482	0.5	0.5
Unit 2	3565	1290	599	361	1725	1914	1241	0.41	0.59
Unit 3	623	18	1	0	36	605	586	0.03	0.97
Saguenay Fjord	69	54	52	12	16	3	1	0.87	0.13
Gulf of Maine	89	0	0	0	0	89	89	0.00	1.00

Table 2.4. Prevalence (%), mean intensity (± SD) and range of intensity of infections of redfish (*Sebastes mentella*) with parasites used as biological tags in the Northwest Atlantic. **N** is the number of fish examined.

Region	*N*	Parasite	Prevalence (%)	Intensity (mean ± SD)	Range
Gulf of St. Lawrence (4T)	*30*	*Anisakis simplex*	53.3	2.8 ± 3.1	1-13
		Hysterothylacium aduncum	20.0	1.2 ± 0.4	1-2
		Sphyrion lumpi	23.3	1.7 ± 0.8	1-3
Cabot Strait (3Pn)	*49*	*Anisakis simplex*	26.5	2.0 ± 1.2	1-4
		Hysterothylacium aduncum	44.9	1.6 ± 0.7	1-3
		Sphyrion lumpi	51.0	1.9 ± 1.4	1-7
Laurentian Channel – Summer (4Vn)	*31*	*Anisakis simplex*	16.1	1.0 ± 0.0	1
		Hysterothylacium aduncum	32.3	1.5 ± 1.0	1-4
		Sphyrion lumpi	67.7	1.7 ± 0.9	1-4
Laurentian Channel – Winter (3Ps)	*31*	*Anisakis simplex*	29.0	1.1± 0.3	1-2
		Hysterothylacium aduncum	29.0	1.4 ± 0.7	1-3
		Sphyrion lumpi	41.9	2.2 ± 2.2	1-9
Labrador (2J)	*13*	*Anisakis simplex*	46.2	25.2 ± 35.5	1-92
		Hysterothylacium aduncum	30.8	7.0 ± 6.8	2-17
		Sphyrion lumpi	7.7	2.0	2
Flemish Pass (3M)	*16*	*Anisakis simplex*	56.3	2.7 ± 3.5	1-12
		Hysterothylacium aduncum	93.8	93.8 ± 92.4	1-259
		Sphyrion lumpi	6.3	10.0	10

Table 2.5. Nonparametric, length stratified comparison of parasite mean abundance in redfish (*S. mentella*) between Unit 1 (Gulf of St. Lawrence) and Unit 2 (Cabot Strait-Laurentian Channel). Overall test multiplicity is corrected for by bootstrap (* = $p < 0.01$).

Parasite	Comparison	Raw *P*-value	Bootstrap *P*-value
Anisakis simplex	Unit 1(summer): Unit 2 (winter)	0.0042	0.0238 *
	Unit 2 (summer): Unit 2 (winter)	0.9150	1.0000
Hysterothylacium aduncum	Unit 1(summer): Unit 2 (winter)	0.9050	1.0000
	Unit 2 (summer): Unit 2 (winter)	0.1613	0.6454
Sphyrion lumpi	Unit 1(summer): Unit 2 (winter)	0.4326	0.9653
	Unit 2 (summer): Unit 2 (winter)	0.4018	0.9517

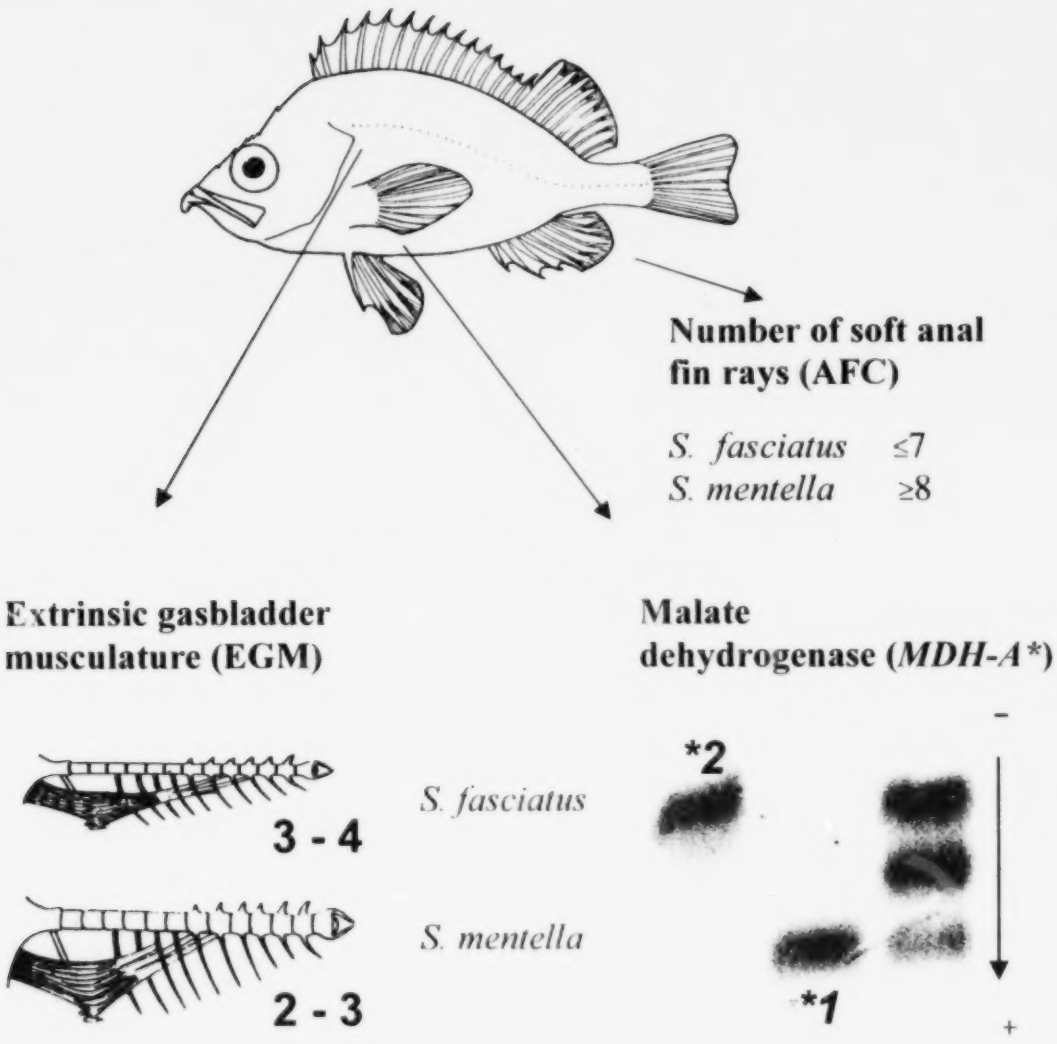


Figure 2.1. Schematic representation of the three criteria (AFC, EGM, MDH) used to discriminate *Sebastes fasciatus* and *S. mentella* in the Northwest Atlantic.

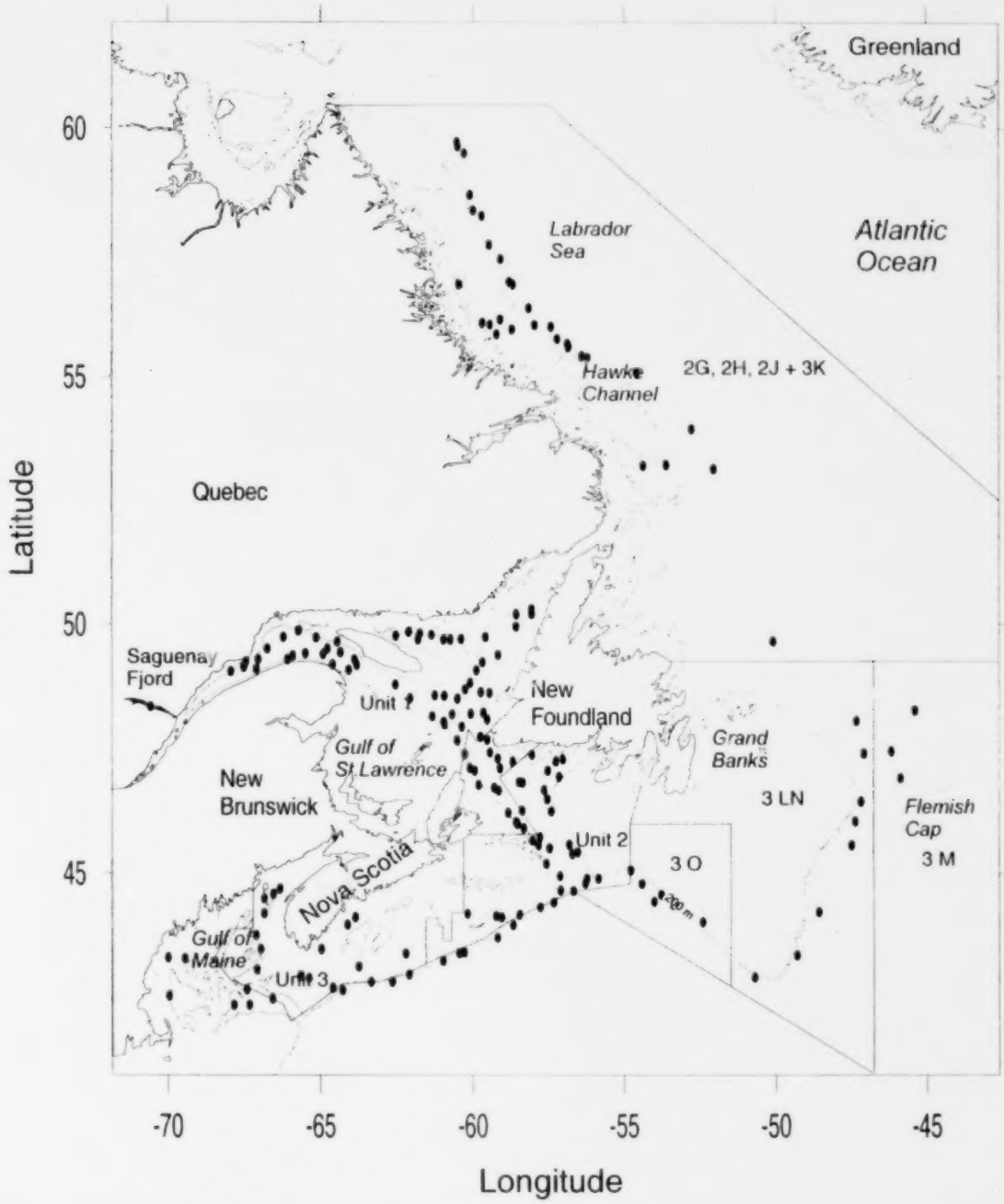


Figure 2.2. Map of the Northwest Atlantic showing the location of the 184 sampling sites representing the 552 bottom trawl tows carried out between 1994 and 1998. All tows that were carried out within a square of 0.5 degree of latitude were pooled regardless of the year of sampling.

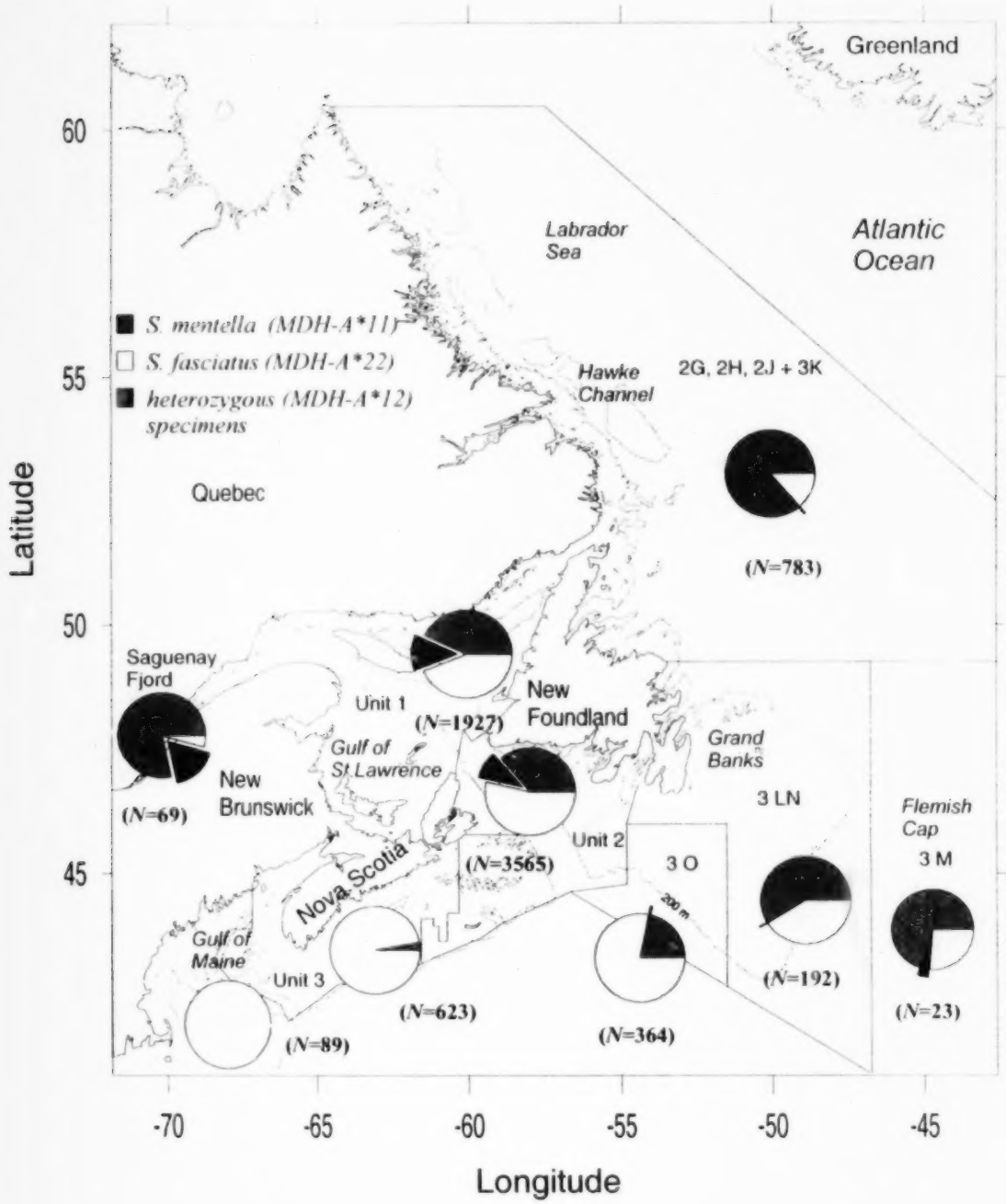


Figure 2.3. Distribution of *Sebastes fasciatus* and *S. mentella* based on the distribution of the three genotypes detected at the *MDH-A** locus in the Northwest Atlantic. The redfish management Units are indicated.

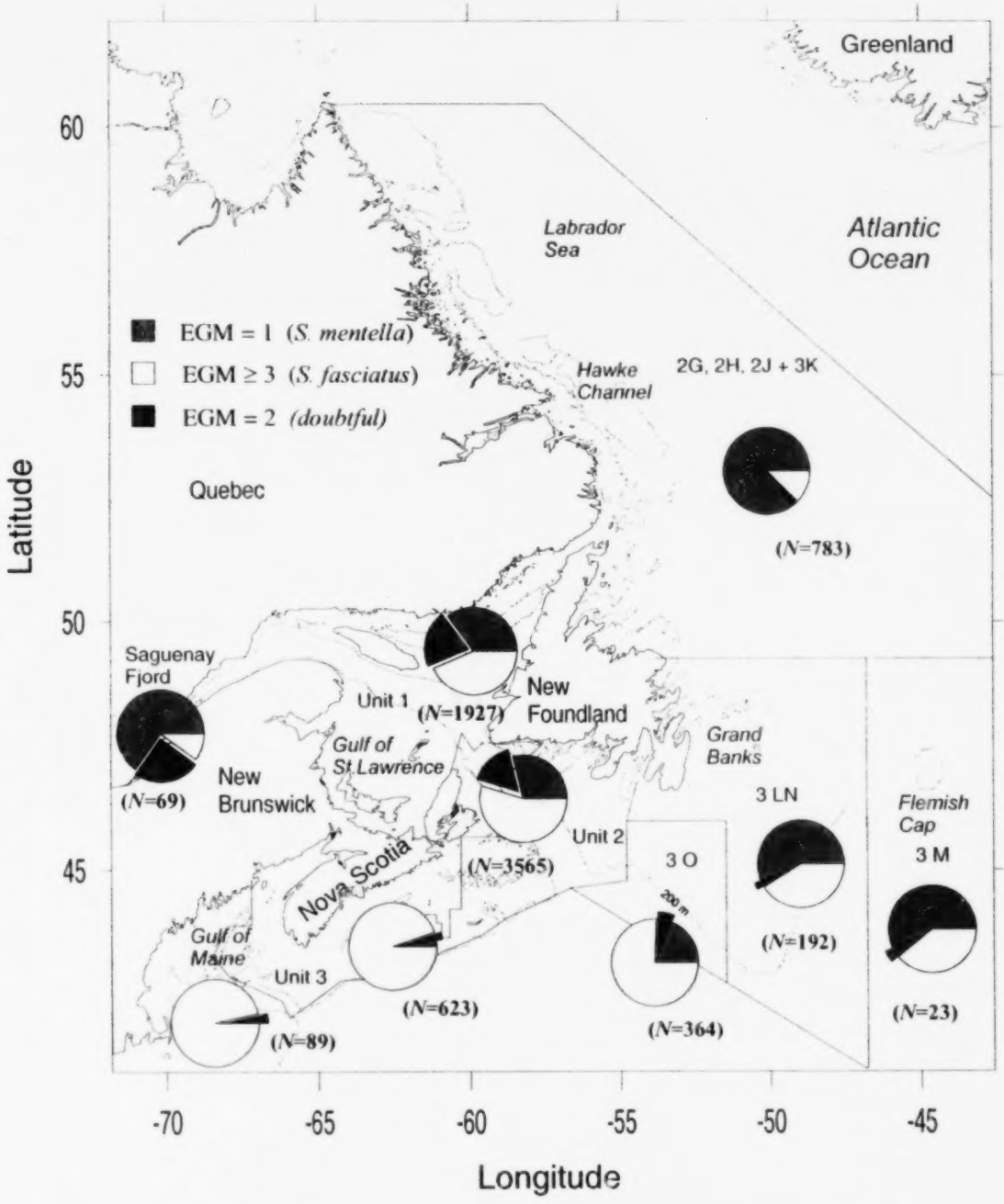


Figure 2.4. Distribution of *Sebastes fasciatus* and *S. mentella* based on the distribution of the gas bladder muscle passage patterns in the Northwest Atlantic. The redfish management Units are indicated. EGM = 1: extrinsic gasbladder musculature passes between ribs 2 and 3 (*S. mentella*); EGM ≥ 3 extrinsic gasbladder musculature passes between ribs 3 and 4 or higher (*S. fasciatus*); EGM = 2 extrinsic gasbladder musculature passes between ribs 2 and 3 and 3 and 4 (doubtful).

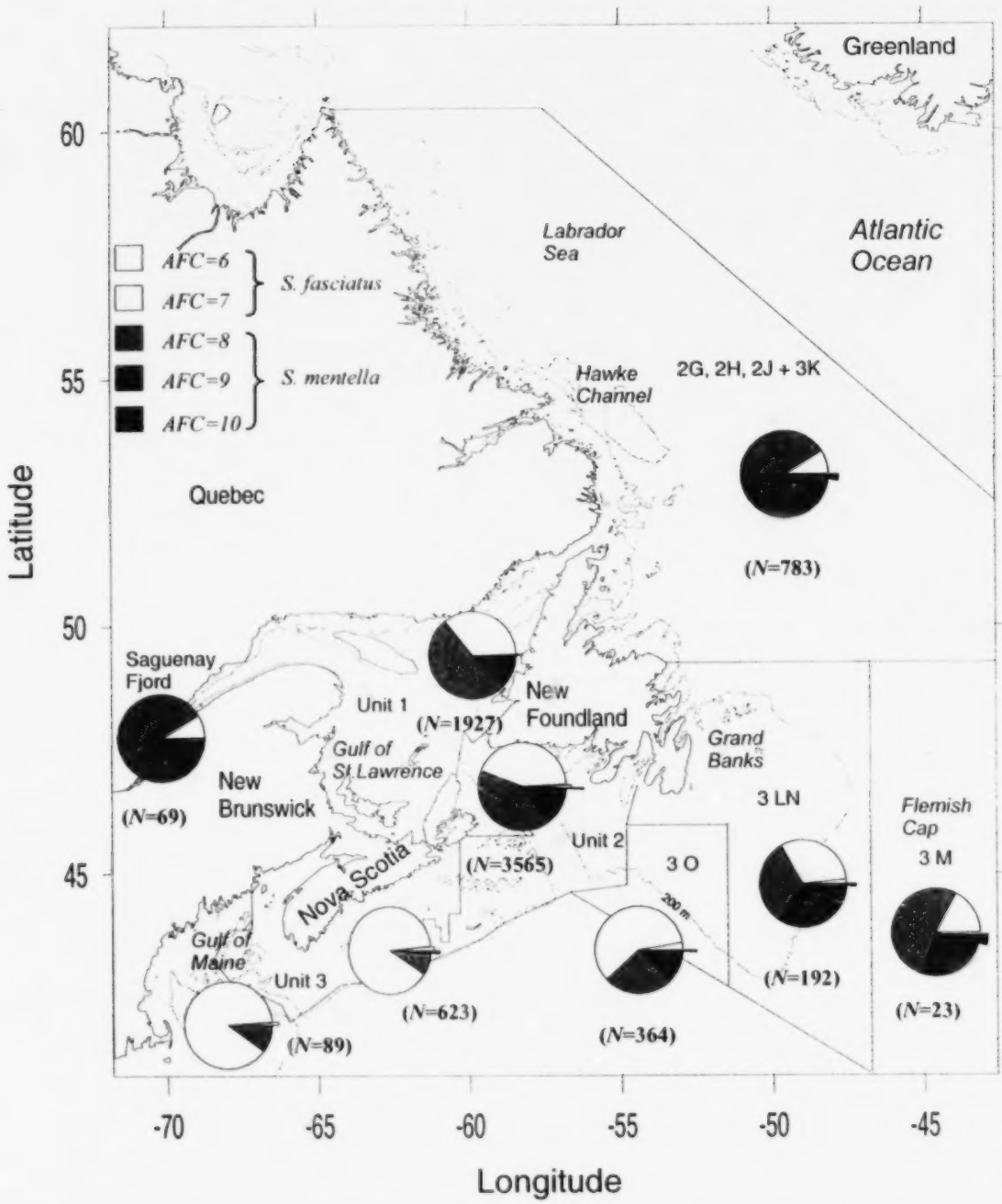


Figure 2.5. Distribution of *Sebastes fasciatus* and *S. mentella* based on the distribution of the number of soft anal fin rays (AFC) in the Northwest Atlantic. The redfish management Units are indicated.

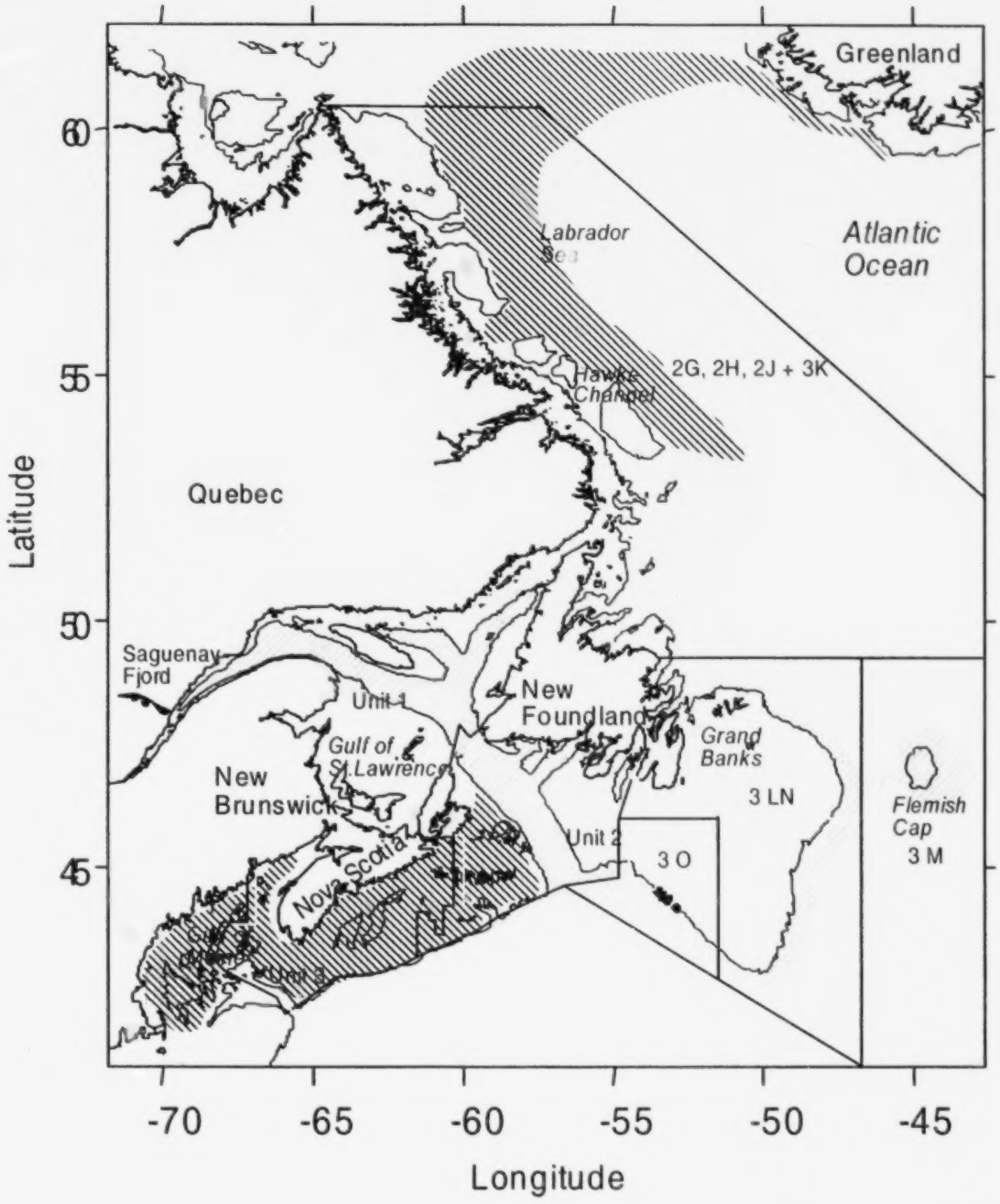


Figure 2.6. Map of the Northwest Atlantic summarising the general distribution of *Sebastes fasciatus* and *S. mentella* based on MDH, EGM and AFC data. The approximate location of the two allopatric (diagonal lines) and of the sympatric (cross-hatched area) areas are illustrated.

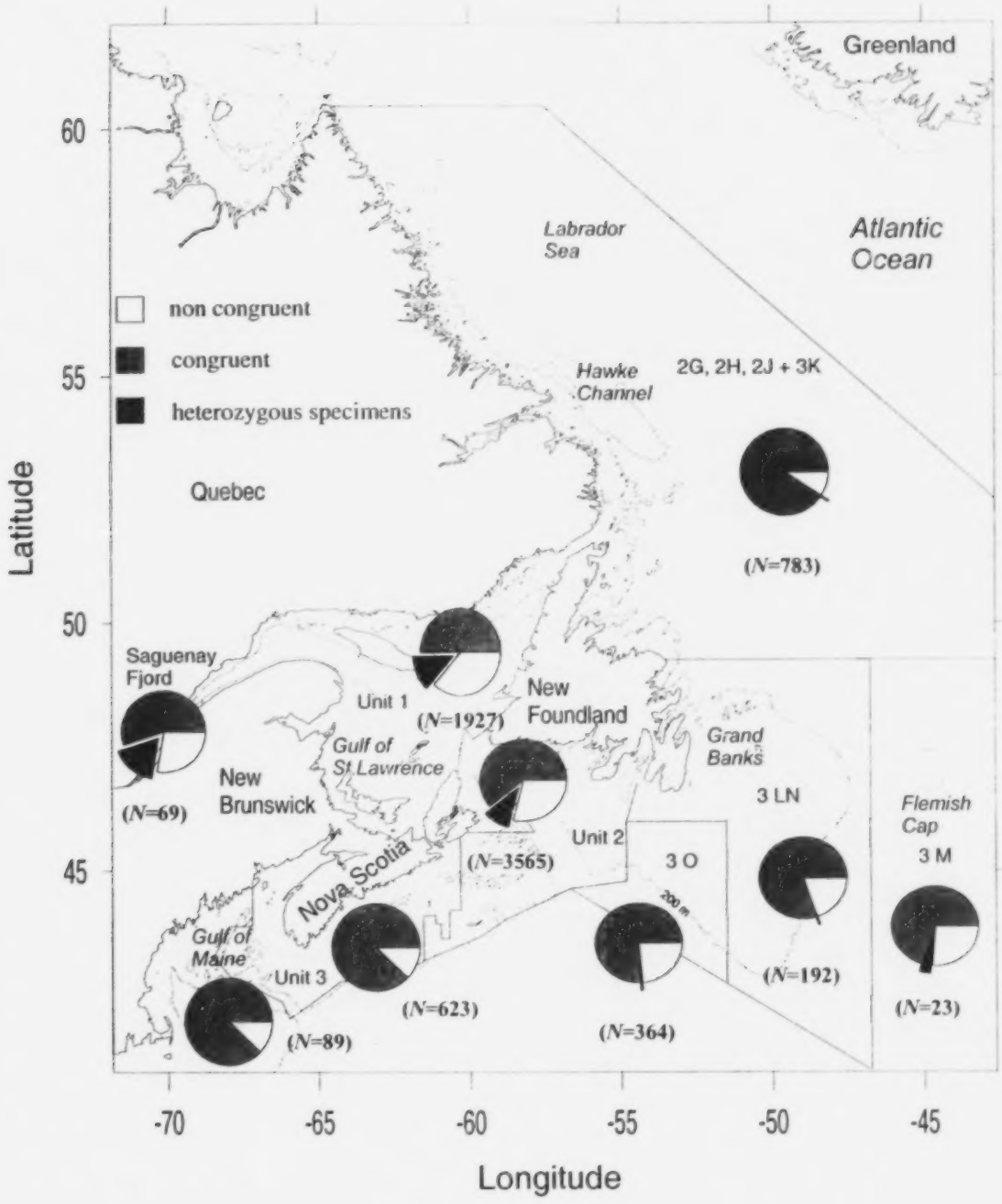


Figure 2.7. Map of the Northwest Atlantic illustrating the degree of congruence among the usual redfish species identification criteria.

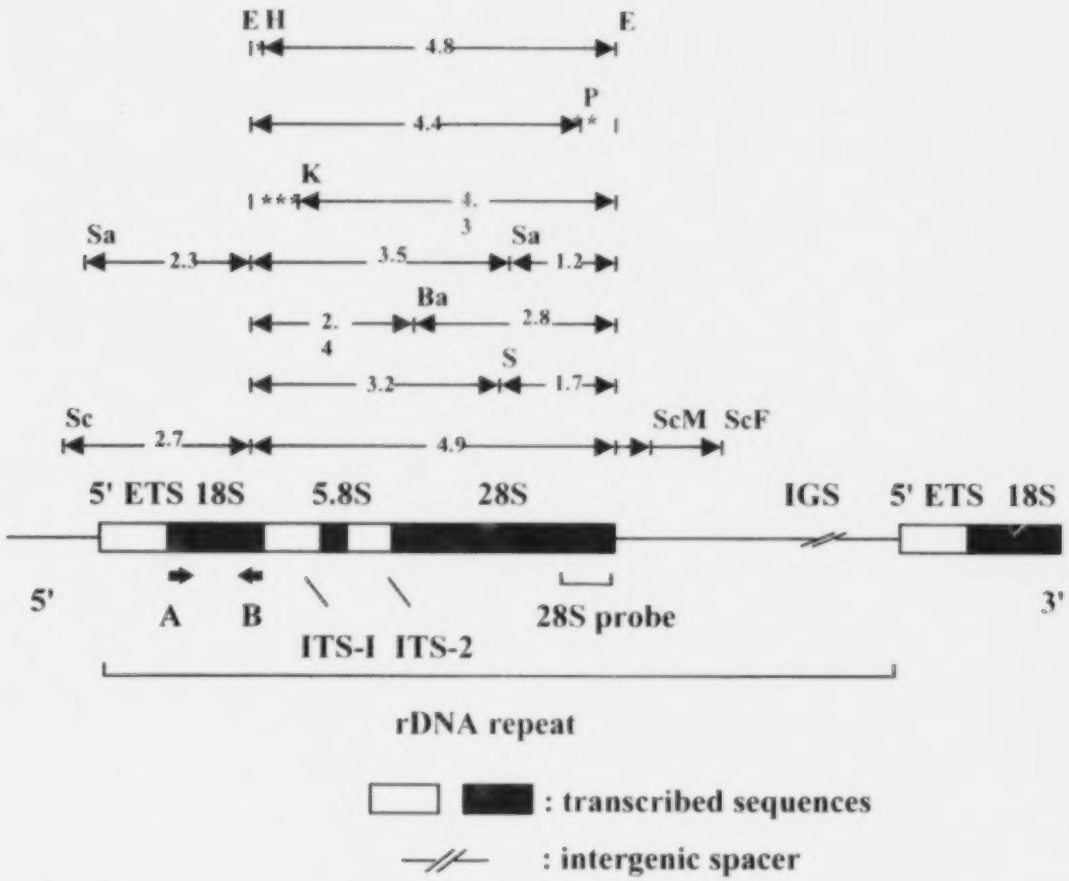


Figure 2.8. Schematic representation of a rDNA repeat Unit. Black boxes represent the coding sequence and the white one the transcribe spacers. The position of the various restriction sites is indicated. The *Sca*I site used for the identification of *S. fasciatus* (ScF) and *S. mentella* (ScM) is also indicated. Letters A and B indicate the approximate position of the primers used to amplify the 18S. The position of the 28S probe is also indicated. ITS: Internal transcribed spacer; ETS: external transcribed spacer; IGS: intergenic spacer. K: *Kpn*I, E: *Eco*RI; S: *Ssp*I, Ba: *Bam*HI, Sa: *Sac*I, Sc: *Sca*I, P: *Pvu*II, H: *Hind*III *: 0.1Kb fragment, **: fragment size is approximately 0.9Kb; ***: 0.6Kb fragment.

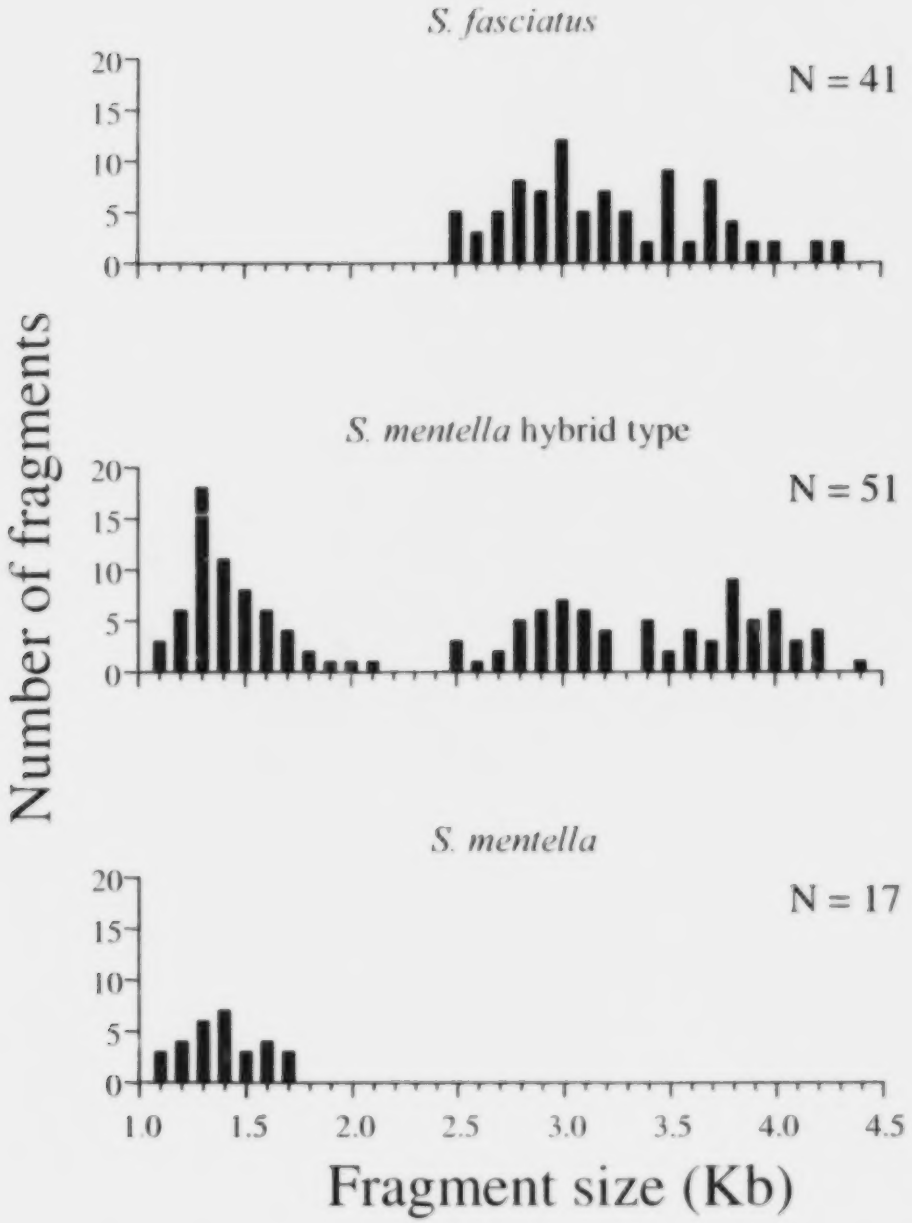


Figure 2.9. Size distribution of the restriction fragments generated by the double digestion *Eco*RI/*Sca*I for the three rDNA groups. N= Sample size.

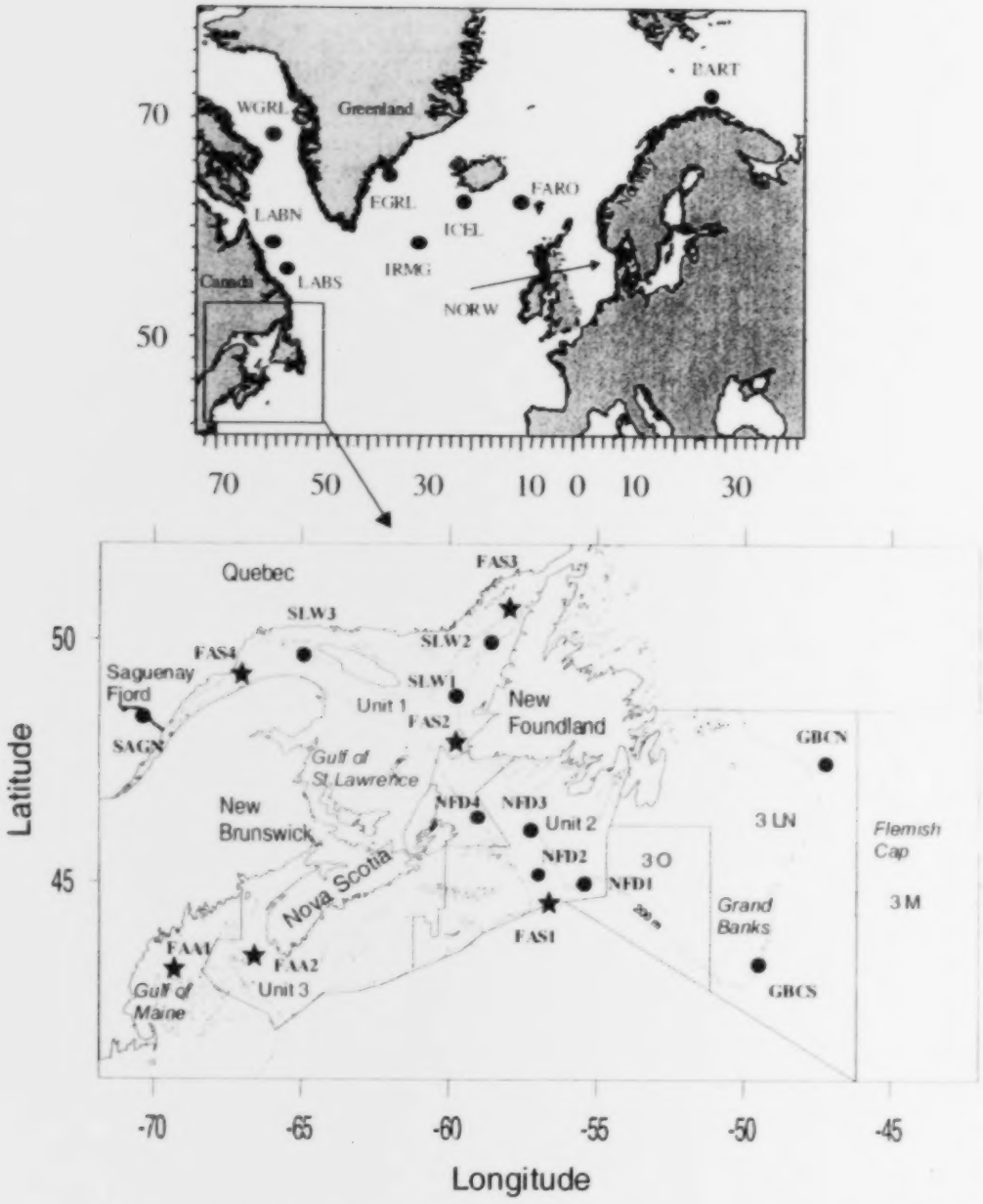
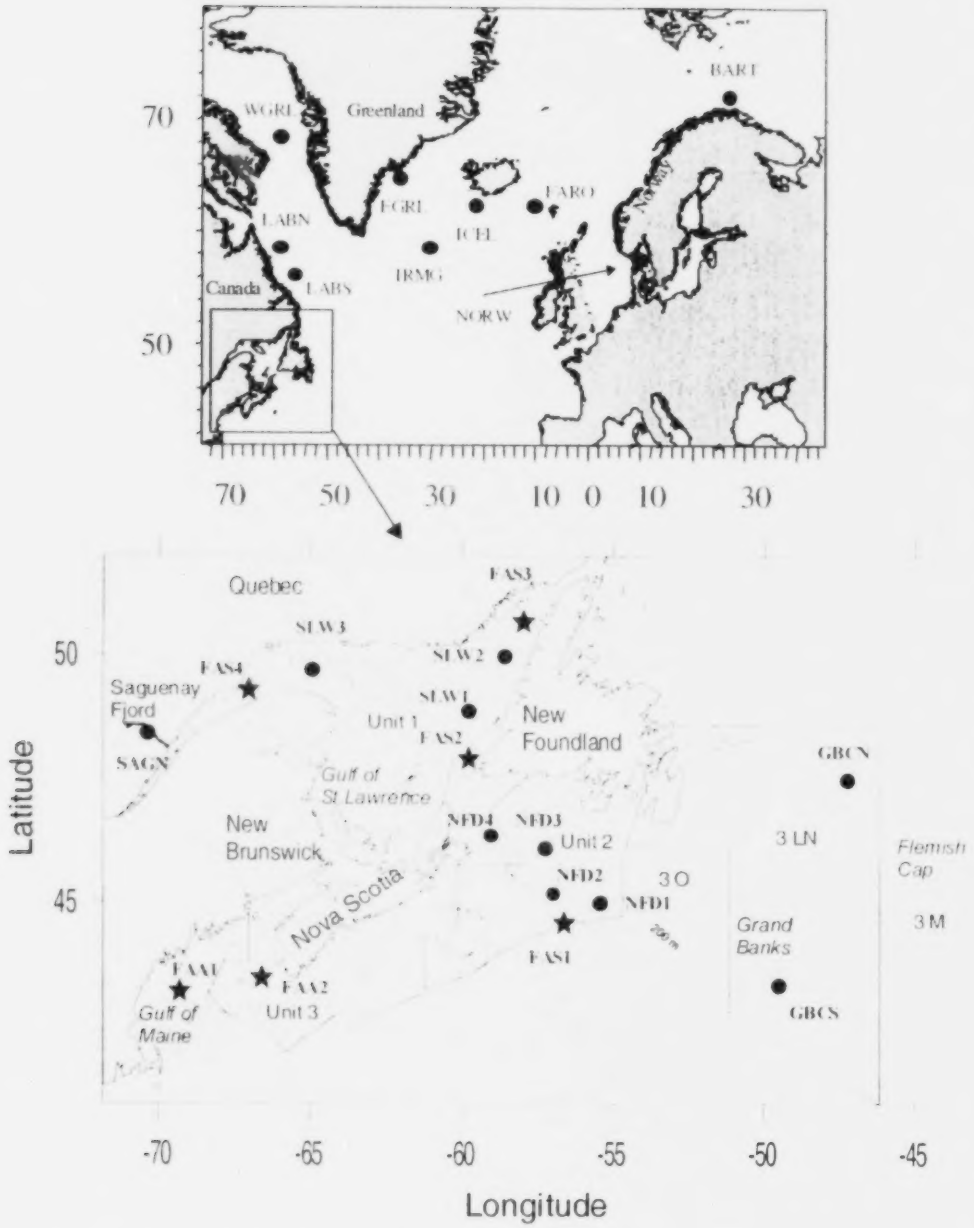


Figure 2.10. Map of the North Atlantic showing the general area where the different samples of *S. fasciatus* (dark stars) and *S. mentella* (dark circles) were collected.

Meaning of site abbreviations is as follows:

For *S. fasciatus*: FAA: *S. fasciatus* in allopatric zone; FAS: *S. fasciatus* in sympatric zone; for *S. mentella*: SAGN: Saguenay Fjord, SLW1, 2, 3: samples from the Gulf of St. Lawrence; NFD1, 2, 3, 4: samples from the Laurentian Channel south of Newfoundland; GBCS: Southern Grand Banks, GBCN: Northern Grand Banks; LABS: Southern Labrador Sea; LABN: Northern Labrador Sea; WGRL: West Greenland; EGRL: East Greenland; IRMG: Irminger Sea; ICEL: Iceland; FARO: Faro Islands; NORW: Norway; BART: Barents Sea.



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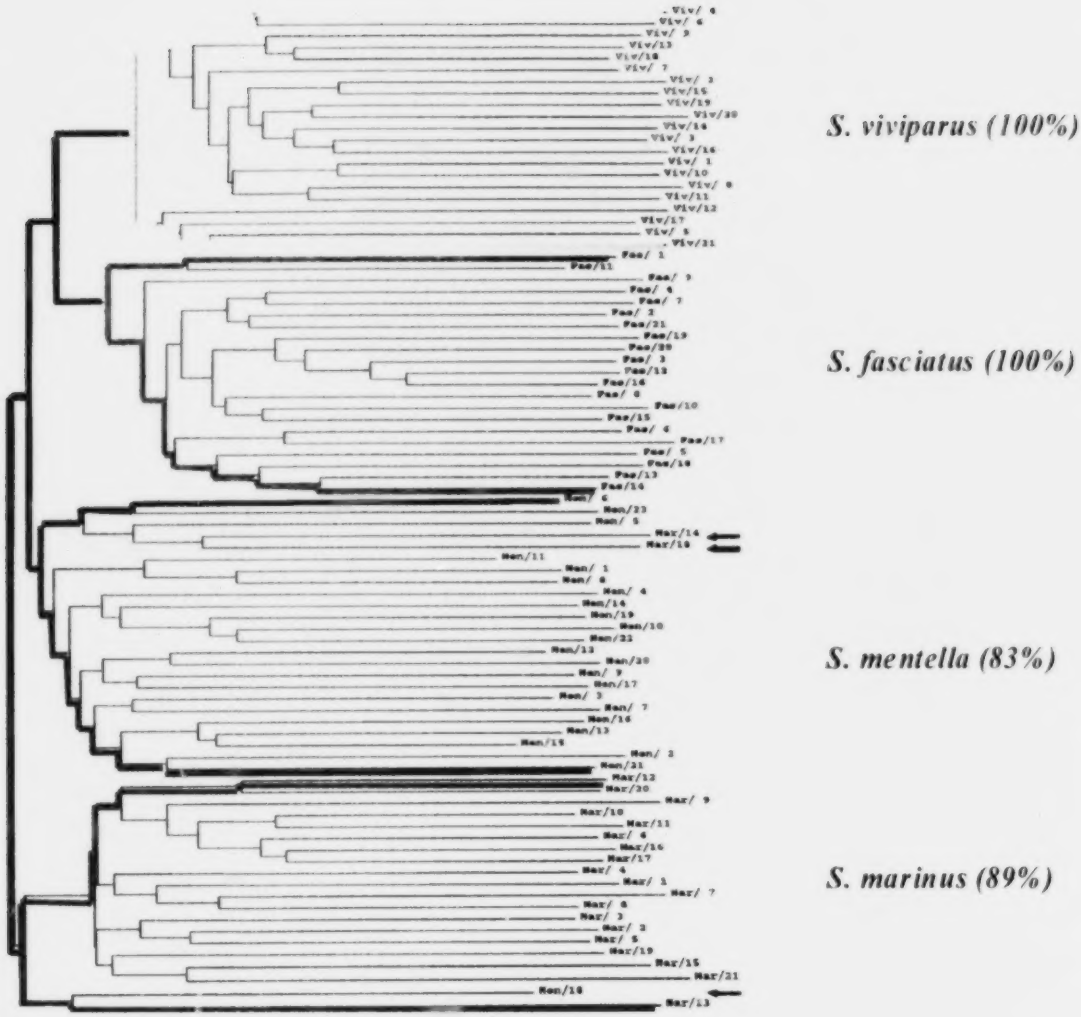

Figure 2.11. Neighbour-joining tree (NJ) of 86 individual redfish based on the allele shared distance. Arrows indicate individuals assigned to the wrong cluster. Values in parenthesis indicate the index of classification for each taxa cluster, based on 260 specimens.

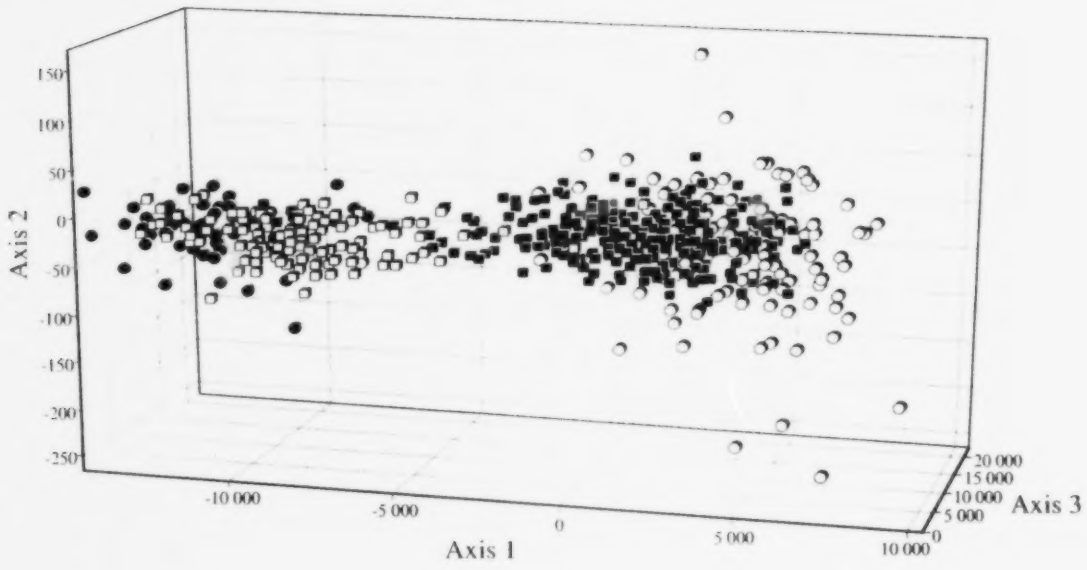

Figure 2.12. Diagram of the Factorial Correspondence Analysis (Principal Component Analysis) showing redfish individuals in a multidimensional space in allopatric and sympatric areas.

(■) *S. mentella* from sympatric area, (●) *S. fasciatus* from allopatric area, (□) *S. fasciatus* from sympatric area, (○) *S. mentella* from allopatric area.

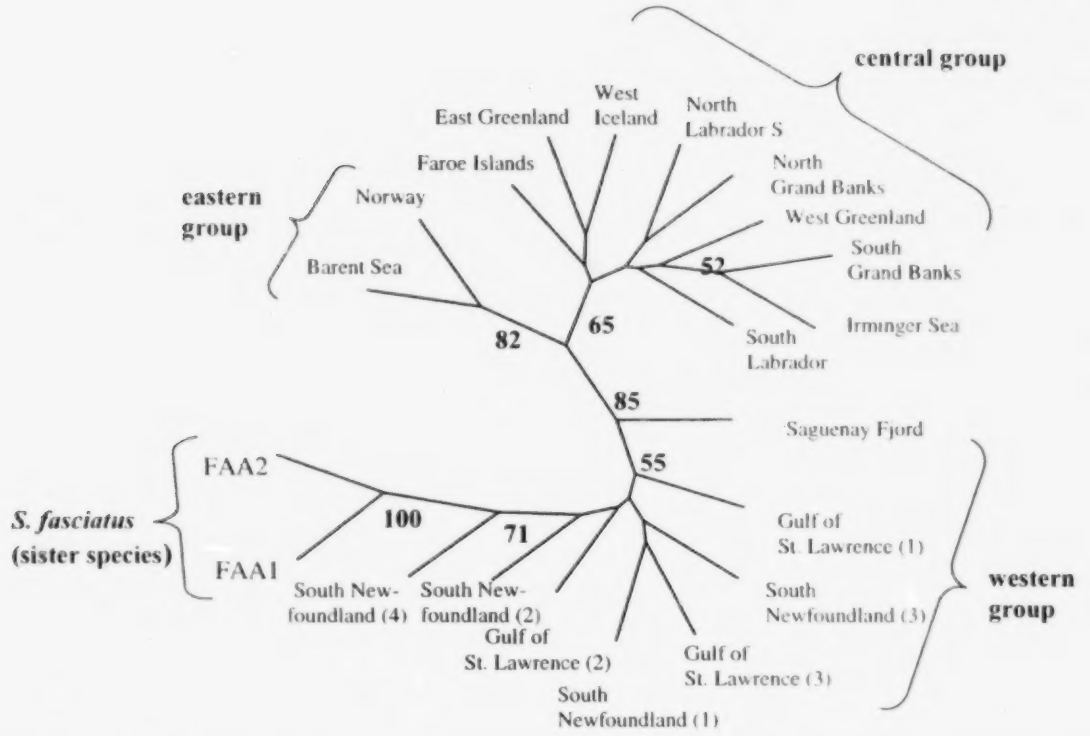

Figure 2.13. Neighbour-joining tree (NJ), based on pairwise Cavalli-Sforza and Edward's (1967) chord distances, illustrating the relationships among the 19 samples of *Sebastes mentella* collected throughout the North Atlantic and two samples of the sister species *S. fasciatus*. Confidence estimates on tree topology (percentage) were obtained by 1000 bootstraps performed by resampling allelic frequencies.

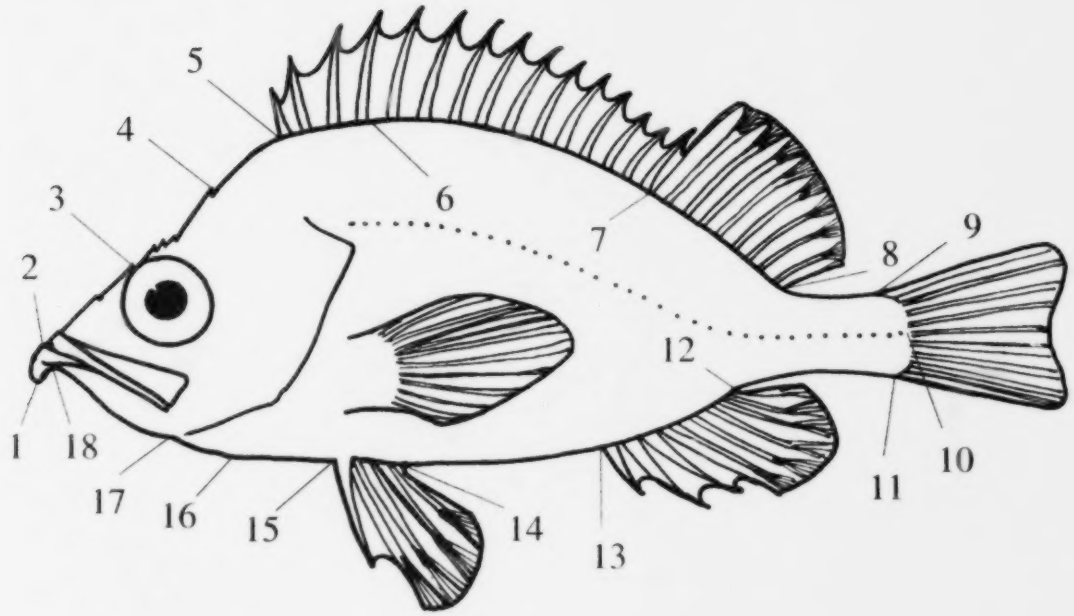

Figure 2.14. The 18 landmarks used in the geometric morphometrics analysis. 1) tip of the symphysial tubercle; 2) bottom of the teeth on the lower jaw; 3) preocular spine; 4) occipital or parietal spine; 5) anterior insertion of the dorsal fin; 6) posterior base of the fourth hard ray on the dorsal fin; 7) posterior base of the last hard ray on the dorsal fin; 8) posterior insertion of the dorsal fin; 9) superior insertion of the caudal fin; 10) posterior extremity of the lateral line; 11) inferior insertion of the caudal fin; 12) posterior insertion of the anal fin; 13) anterior insertion of the anal fin; 14) posterior insertion of the pelvic fin; 15) anterior insertion of the pelvic fin; 16) inferior extremity of the pectoral girdle; 17) posterior extremity of the lower jaw; 18) inferior insertion of the symphysial tubercle.

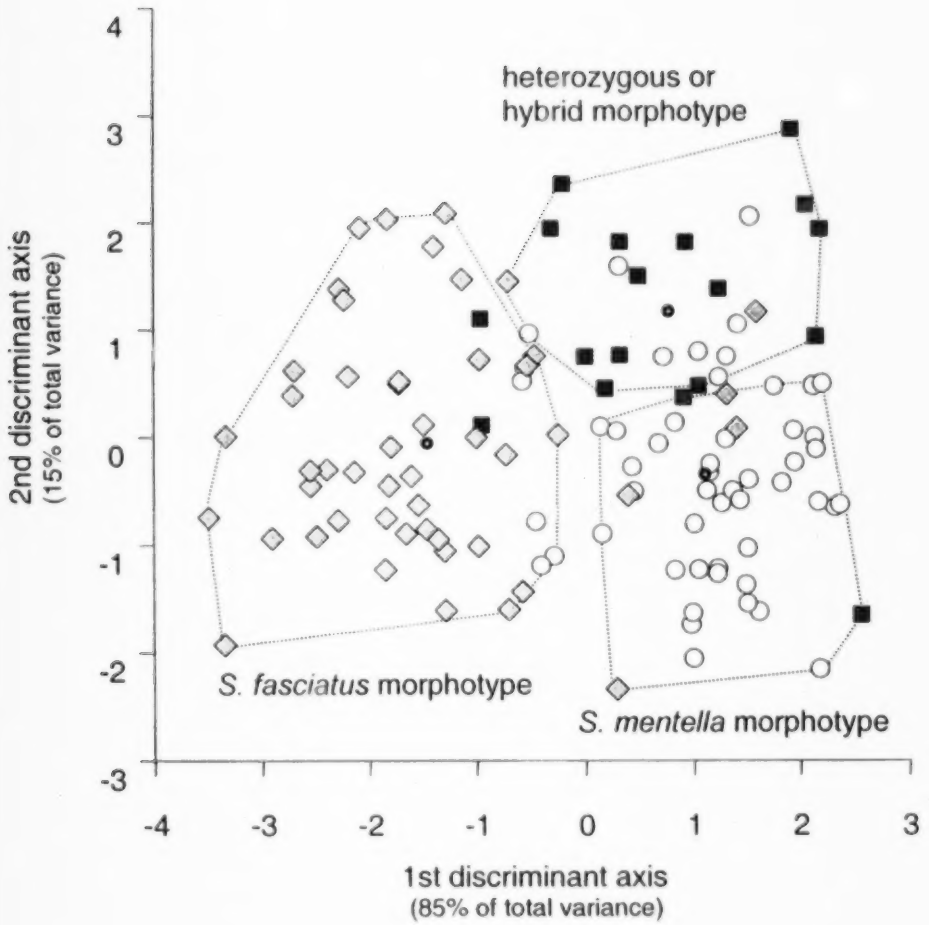

Figure 2.15. Specimen coordinates of *S. mentella* (○), *S. fasciatus* (◇), and of heterozygous individuals (■) on the two discriminant functions determined from morphometric data. Coordinates of the body shape mean of each genotype are illustrated (◘).

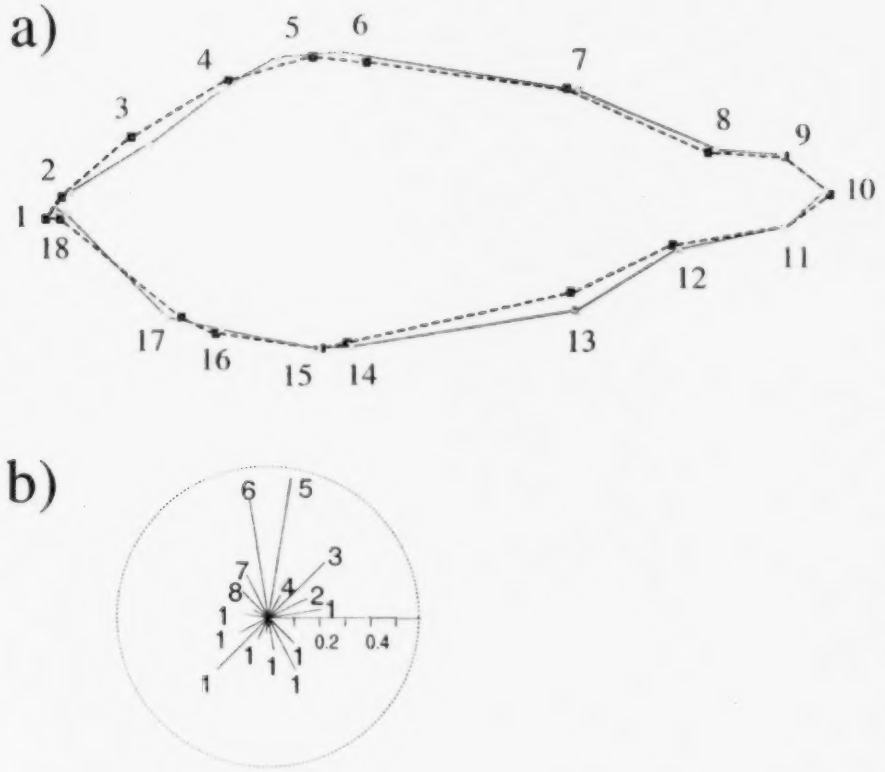

Figure 2.16. **A)** Mean configuration for the 52 *S. mentella* specimens (------) and the 49 *S. fasciatus* specimens (——) after size standardisation and procrustes superimposition; **B)** Polar diagram illustrating the amplitude of movement at each landmark between the mean configurations of *S. mentella* and *S. fasciatus*.

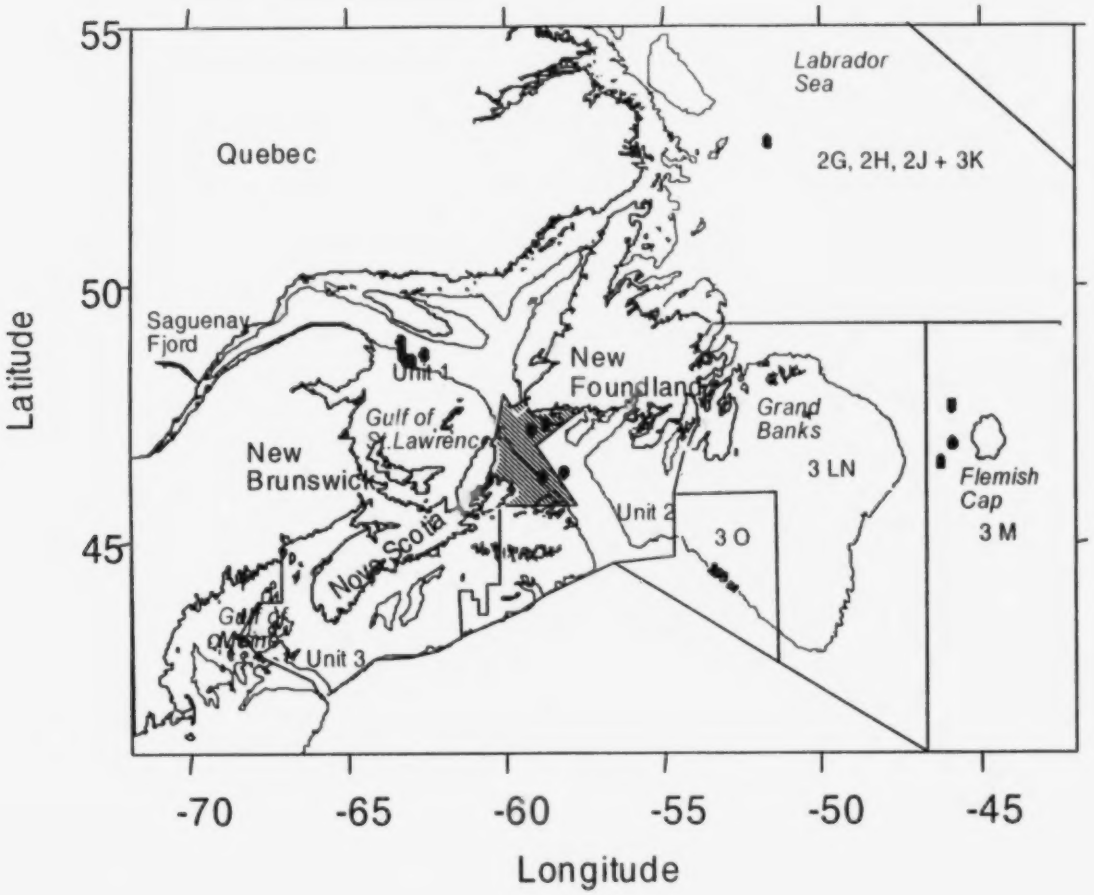

Figure 2.17. Map of the Northwest Atlantic showing the sampling sites for the parasite study. Overlap area (subDivisions 3Pn and 4Vn shown in hatched).

III. IMPROVED STOCK ASSESSMENT AND MANAGEMENT APPROACHES

3. Standardised Inter-Regional Redfish survey Sampling and Analysis of Growth and Maturity in Management Units 1,2,3 & NAFO Div 3O

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3.1 Introduction

This project was conducted by the biologists and technicians at the three DFO research laboratories which have been assigned responsibility for ongoing assessment of Unit 1, 2, 3, and NAFO division 3O redfish. The key events in this project are presented in Table 3.1.

3.2 Results

Description of the data

Prior to inception of the high priority program, standard DFO survey practice in some regions only called for the recording of redfish sex, length and weight. As part of the high priority program, a number of other observations were made. These were: number of soft rays in the anal fin (AFC), gas bladder muscle structure (EGM), malate dehydrogenase enzyme (MDH), age and maturity stage (Table 3.2).

Geographic distribution of the species

Management Units 1 and 2 samples contained *S. mentella*, *S fasciatus* and heterozygous specimens(Figure 3.1). Unit 3 samples contained mostly *S. fasciatus* specimens, only a few *S. mentella* and no heterozygotes. NAFO Division 3O samples contained mostly *S. mentella* and *S. fasciatus* specimens and only a few heterozygotes.

Length at age

Sebastes mentella are indistinguishable from heterozygotes in terms of observed length at age (Figure 3.2) thus comparisons of *S. fasciatus* with *S. mentella* apply equally to heterozygotes. In composite, redfish are the same length at a given age regardless of sex and species up to age 10 (25 cm). After 10 years, females are longer at age than males of the same species. *S. fasciatus* are shorter than the *S. mentella* of the same age and sex.

Sebastes mentella are about the same length as *S. fasciatus* of similar sex and age in a given area. *Sebastes mentella* in Unit 1 and the Cabot Strait portion of Unit 2 and on the South Grand Banks are older and thus larger than the *S. fasciatus* found there. *Sebastes fasciatus* in the Scotia Shelf Basins and on the South Grand Banks do not grow as large as those in other areas.

Fish of age 16 from Units 1 and 2 samples were selected to conduct a statistical examination of length differences by management unit, species, and sex. Length differences between sexes (1.2 cm) and between *S. mentella* and *S. fasciatus* (1.8 cm) were significant but management Units were not. Interactions were not significant.

Age and length at maturity

Males of a species mature 1-2 years earlier than females, while *S. fasciatus* of a given sex mature a 1-2 years earlier than *S. mentella* of the same sex (Figure 3.3). Males of a species mature at size which is 3-5 cm smaller than females, while *S. fasciatus* of a given sex mature at a size which is 1-3 cm smaller than that of a maturing *S. mentella* (Figure 3.4). *Sebastes fasciatus* males mature at a younger age and smaller size than the either the female *S. fasciatus* or the male and female *S. mentella*.

Previous Studies

Ni and Sandman (1984) examined redfish length at maturity using data from the whole Northwest Atlantic between 1957-69. Sample sites were mainly along the continental slopes and analyses were conducted on two groups: *S. marinus* and beaked redfishes (*S. mentella* and *S. fasciatus* combined). Mayo *et al* (1990) derived redfish growth and maturation rates for redfish (*S. fasciatus*) using data from the Gulf of Maine-Georges Bank region between 1975-80. Both studies noted geographical variation but overall, the sizes at maturity for female redfishes were larger than that of males. In addition, Ni and Sandeman (1984) noted that size at maturity of female *S. marinus* was larger than that of beaked redfishes whereas in males there was no significant differences between groups. Data from the present study provides coverage for Scotian Shelf Basins which were not sampled by either

of the previous studies and permits comparison between *S. fasciatus* and *S. mentella*. A direct comparison of the three studies is outstanding.

3.3 Conclusions

Standardised inter-regional redfish survey sampling protocols were developed and successfully used on DFO research surveys between 1996-98. Routine ongoing application of the enhanced survey sampling protocols in all of the management Units may not be necessary. Unit 3 for example contains mostly *S. fasciatus* and therefore it is clearly not necessary to continue routine application of the enhanced sampling protocol in that area.

The data and new knowledge resulting from these protocols can be used to examine a number of outstanding issues. These are: appropriateness of present management Unit boundaries, an evaluation of present multi-species approach to redfish management, and development of yield per recruit models on which to base improved management strategies.

Table 3.1. Key events of the Standardised Inter-Regional Redfish survey Sampling and Analysis of Growth and Maturity in Management Units 1,2,3 & NAFO Div 3O project.

1995	Atlantic Zone Redfish Sampling Strategy Workshop at the Bedford Institute of Oceanography (BIO).
1996	Redfish Survey Sampling Guide produced at BIO.
1996-98	Enhanced sampling on 14 surveys by the 3 regions. - 6,000 enhanced samples collected - 4,000 tissue samples analysed at the Maurice Lamontagne Institute (IML) - 2,000 otoliths read at the Northwest Atlantic Fisheries Centre (NWAFC)
1999	Data consolidation and analysis at BIO

Table 3.2. Number of redfish samples by management Unit and type of sample. Species: species were identified using either number of soft rays in the anal fin, Gas bladder musculature or MDH allele composition; Age: age determination was performed; Maturity: maturity state was determined.

Management Unit	**Species**	**Species & age**	**Species, age & maturity**
Unit 1	1430	500	434
Unit 2	1822	1016	983
Unit 3	608	544	336
Div 3O	84	84	84
Total	3944	2144	1837

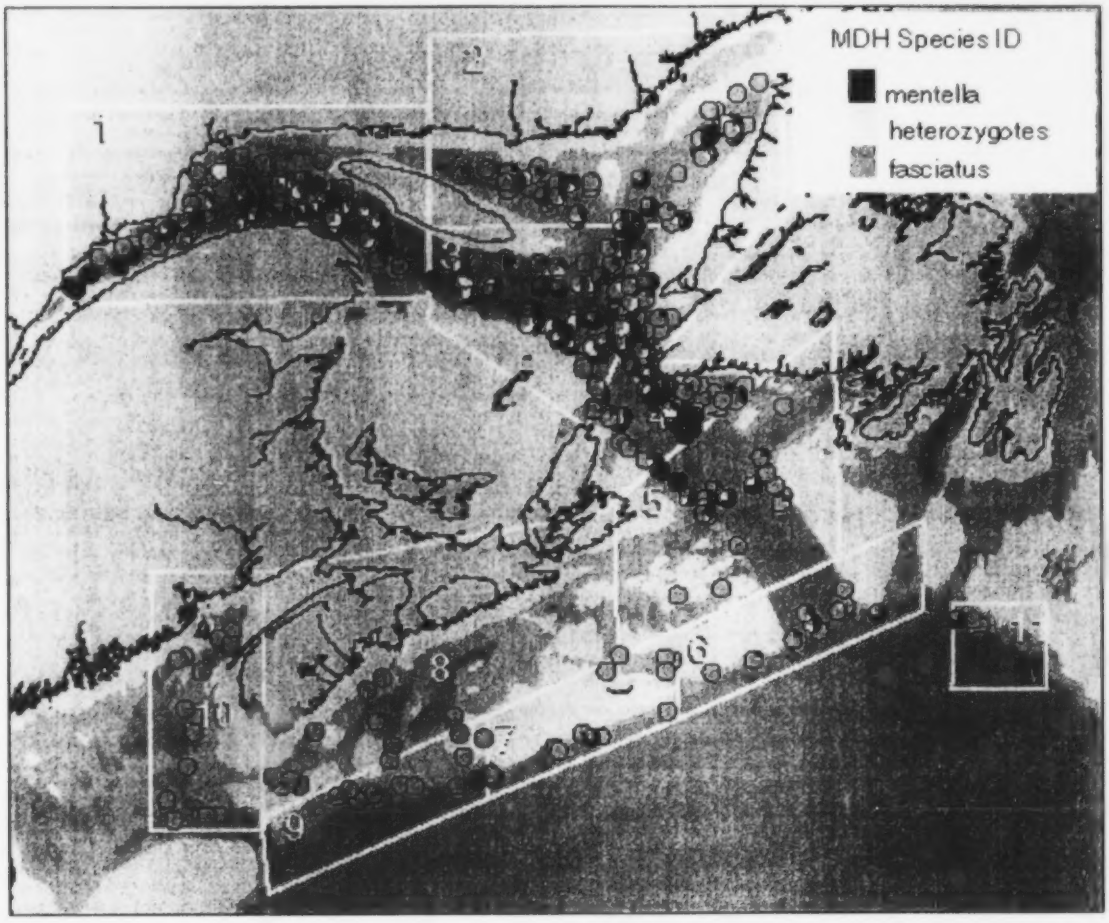

Figure 3.1. Geographical distribution of *S. fasciatus* and *S. mentella* based on the distribution of the three genotype detected *MDH** locus in Unit 1 and 2.

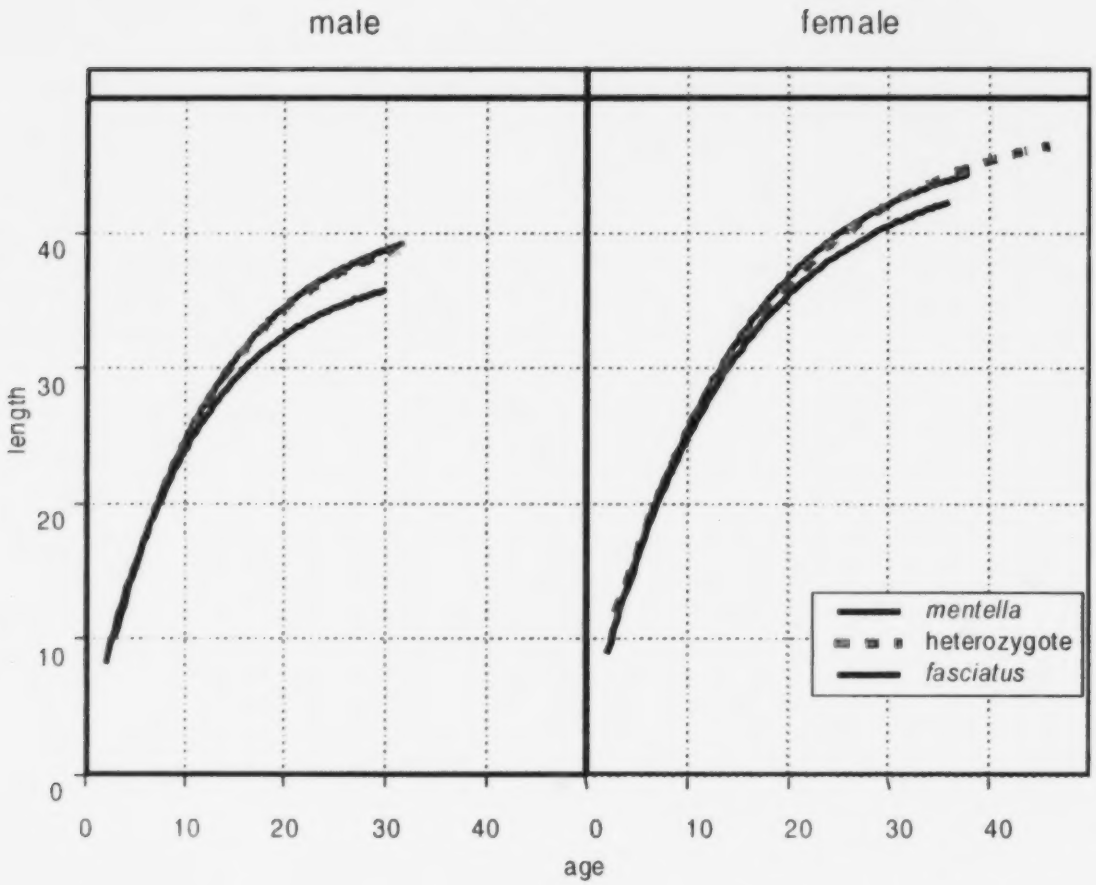

Figure 3.2. Redfish length at age by sex and species as indicated by variability at the *MDH** locus.

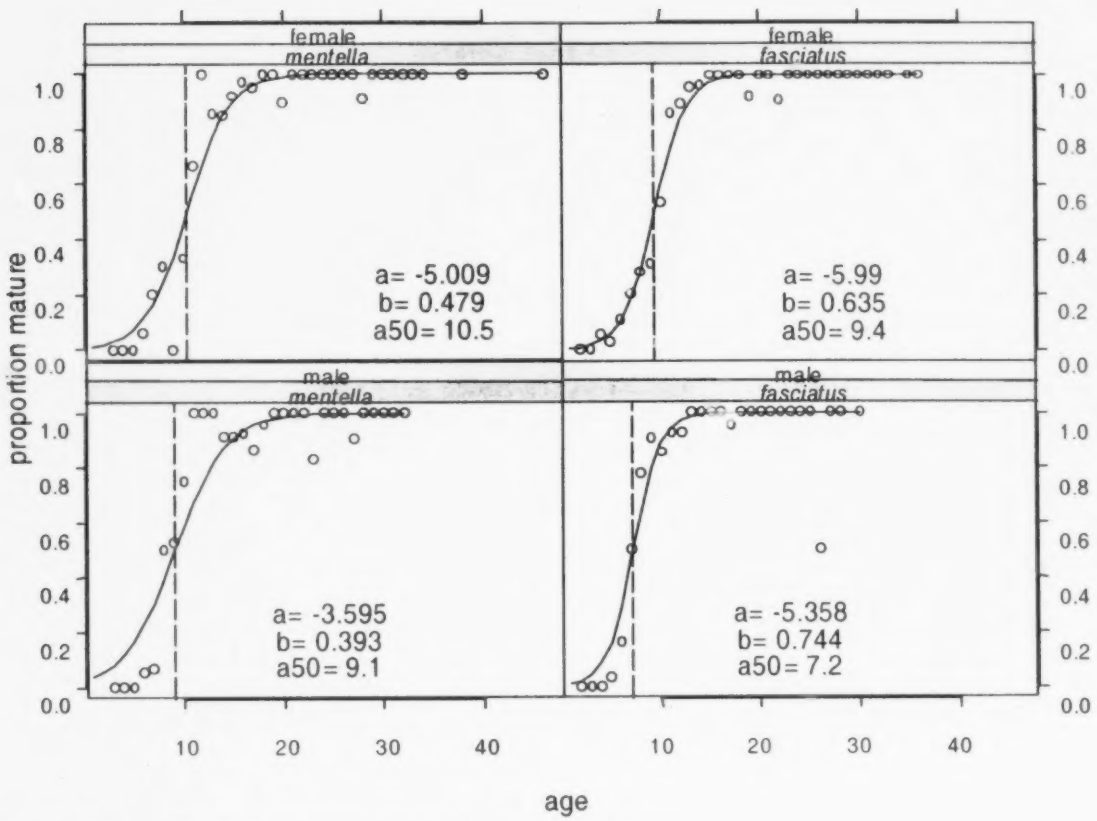

Figure 3.3. Redfish maturity at age by species and sex.

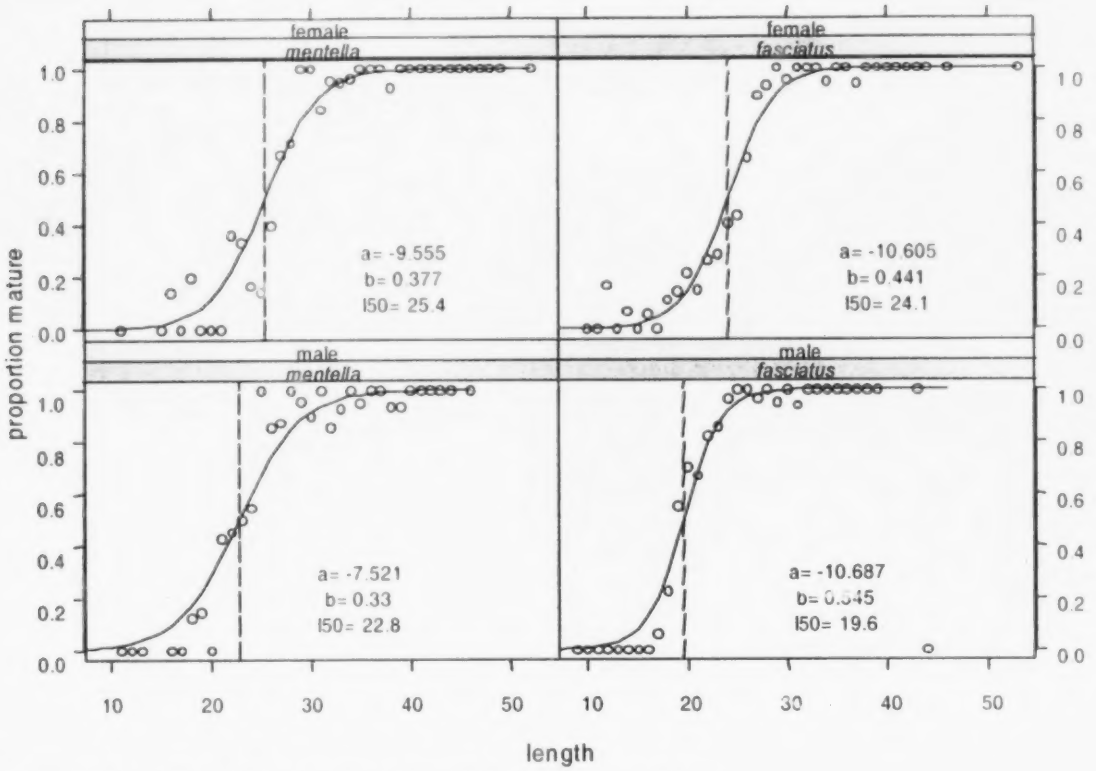

Figure 3.4. Redfish maturity at length by species and sex.

4. Retrospective Analysis of Redfish Catch Distribution: Inferences on redfish migrations through an analysis of commercial logbook information for Management Units 1-3 from 1988-1992

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4.1 Introduction

Prior to 1993, redfish were managed as three units: Division 3P, Divisions 4RST and Divisions 4VWX. In 1989 the integrity of these units as separate management areas was questioned and an examination of applicable data and pertinent published studies ensued. This resulted in the proposal of new management units believed to have a firmer biological basis than the former units (see CAFSAC (1991); Atkinson and Power (1990, 1991)).

One of the analyses that formed part of the reasoning in revising the management boundaries was based on commercial fishery catch rate distribution. An initial examination consisted of information for 1981-1990 from regional observer databases (Atkinson and Power, 1991). The data supported the conventional wisdom that fish move into the Cabot Strait area in winter and returned later in the spring. A more recent analysis (Morin. *et al*, 1994) utilised catch and effort data for 1990-1993 from regional databases of DFO statistics branches (Maritimes and Quebec regions) supplemented by observer data for the Newfoundland Region. This analysis supported the results of Atkinson and Power (1991) and further suggested, with some caution, that migration of fish into the Cabot Strait area (southern 4RS, northern 3Pn4Vn) may have occurred as early as November.

Under the multidisciplinary research program on redfish, a database was compiled of logbook data from the Newfoundland Region. This enabled a revision of the distribution of catch rate information based on commercial logbooks.

4.2 Materials and Methods

Information was compiled on a set by set basis for logbooks from 1985 to 1992 submitted to the Newfoundland Region. Logbook information was also obtained from the

Gulf region (1985-1993), the Quebec Region (1989-1994) and the Maritimes Region (1988-1998). Information about position of catch is available from all regions Statistics Branches since 1993. However, it was decided to only consider the data from 1988-1992 because (1) this is the period prior to the implementation of the revised management units, and (2) this is the only overlap between the various databases. The only exception to this is the elimination of the 1990 Quebec data because position information was lacking.

The Gulf and Quebec data were identified to the level of a 10 minutes of latitude by 10 minutes of longitude square. The Maritimes and Newfoundland data were recoded according to this grid. All datasets were consistent by containing information on both directed fisheries and those in which redfish was recorded as a bycatch. These data were summed together by grid position and week over all years, and a catch rate calculated using effort in hours fished. Only otter trawl fisheries were considered. The data were plotted as representative circles with ACON (Black 2001) by week and grid position. Because of the variability of catch rate by grid by week, the data were grouped into categories. The sizes of the circles were proportional to the median of the category.

4.3 Results

In total, the logbook data represent about 72% of the total landings. Since the data cover 1988 to 1992 it is assumed that the general migrations implied, were primarily for the relatively strong 1980-dominated year classes in Unit1 and Unit 2. The following generalisations can be made based on the derived catch rate by week and grid (Figure 4.1 to Figure 4.9):

Dense aggregations were seen in the Cabot Strait area (Figure 4.1) from about the junction of Divisions 4RST into subdivisions 3Pn and partially in north-eastern 4Vn, and were generally persistent to about mid April. There was a tendency to move further away from the mouth of the Gulf by mid-February (Figure 4.2).

About the beginning of April, there appeared to be a shift into 4Vn and back into the mouth of the Gulf. At about the same time there was an increase in the density of fish in the channel area of 4Vs adjacent to 4Vn. By the first of May there were dense aggregations in this area (Figure 4.3).

By the end of April, the aggregations in the Cabot Strait area had moved further into the Gulf and although not as dense as in January they occupied about the same position (Figure 4.3).

At mid-May, there was an aggregation at the junction of Divisions 4RST, one to the north-west in Division 4S but the largest relative aggregation was in the 4Vs channel area. The 4Vs aggregation had dispersed by the end of June (Figure 4.4).

Catches were spread throughout the Gulf during summer but the highest consistent catch rates were south-east of Anticosti at the 4RS border in deeper water at about

49° N. This was persistent until early September. Except for a few areas along the slopes, the Quebec channel area had a relatively lower but stable density compared to the Gulf (Figure 4.5 and Figure 4.6).

By mid-September, there appeared to be an aggregation forming in southern 3Pn in the Burgeo Bank area. This persisted until the third week of October then disappeared. The 4RS aggregation was still at about the same general area until about mid-October (Figure 4.7).

The 4RS aggregation appeared to shift further to the south by mid-November and extended into 3Pn/4Vn. The aggregation remained reasonably stable in the area until the end of December (Figure 4.8 and Figure 4.9).

The total data from 1988-1992 were also plotted by grid across all years for effort (Figure 4.10) and catches (Figure 4.11). The pattern generally indicated that most of the effort occurred in water over 300 m. It is also clear that the southern 4R3Pn area over 300 m, about $^1/_6$ of the whole area in Unit 1 and Unit 2 over 300 m, had received the most effort and had taken most of the catch based on the logbook data which accounts for 72% of the landings.

4.4 Conclusions

The logbook data support previous analyses regarding migrations from the Gulf into the Cabot Strait area. It also suggests that the timing of these migrations, on average over the 1988-1992 period, had started southward by mid-November and northward by mid-April. This suggests that a practical time frame for these migrations is more likely between November to May. There were also clear indications of an increasing aggregation at the 4Vn/4Vs border over April, at around the same time as the northward movement into the Gulf. This aggregation persisted with high density until the end of June. Because the general lack of 3Ps data south of Hermitage Channel, it is difficult to the movement of these fish later in the year, but it doesn't appear to be associated with the Gulf migration. There was a similar pattern of an emergence of an aggregation at the 3Pn/3Ps border in mid-September which had dispersed by mid-October, just prior to the southward migration into the Cabot Strait area. This is again difficult to interpret.

4.5 Acknowledgement

The author would like to thank G. Poirier (Gulf Region, Science), B. Morin (Quebec Region, Science) and P.R. Smith (Maritimes Region, Statistics) for their provision of the logbook dataset and guidance with its use.

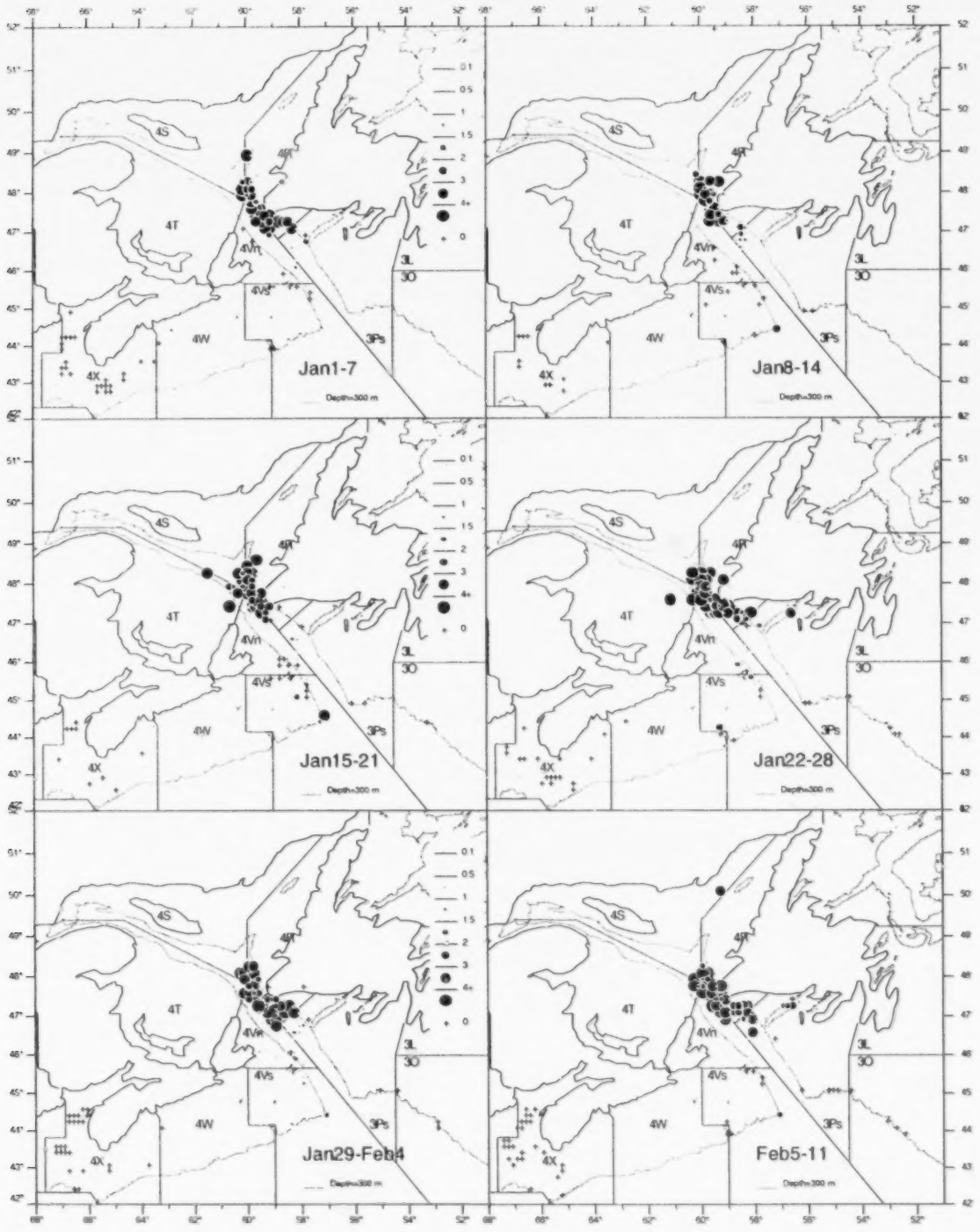

Figure 4.1. Distribution of redfish catch rates (tons/hour) based on commercial logbook information from 1988-1992 summarised by 10' squares, continued.

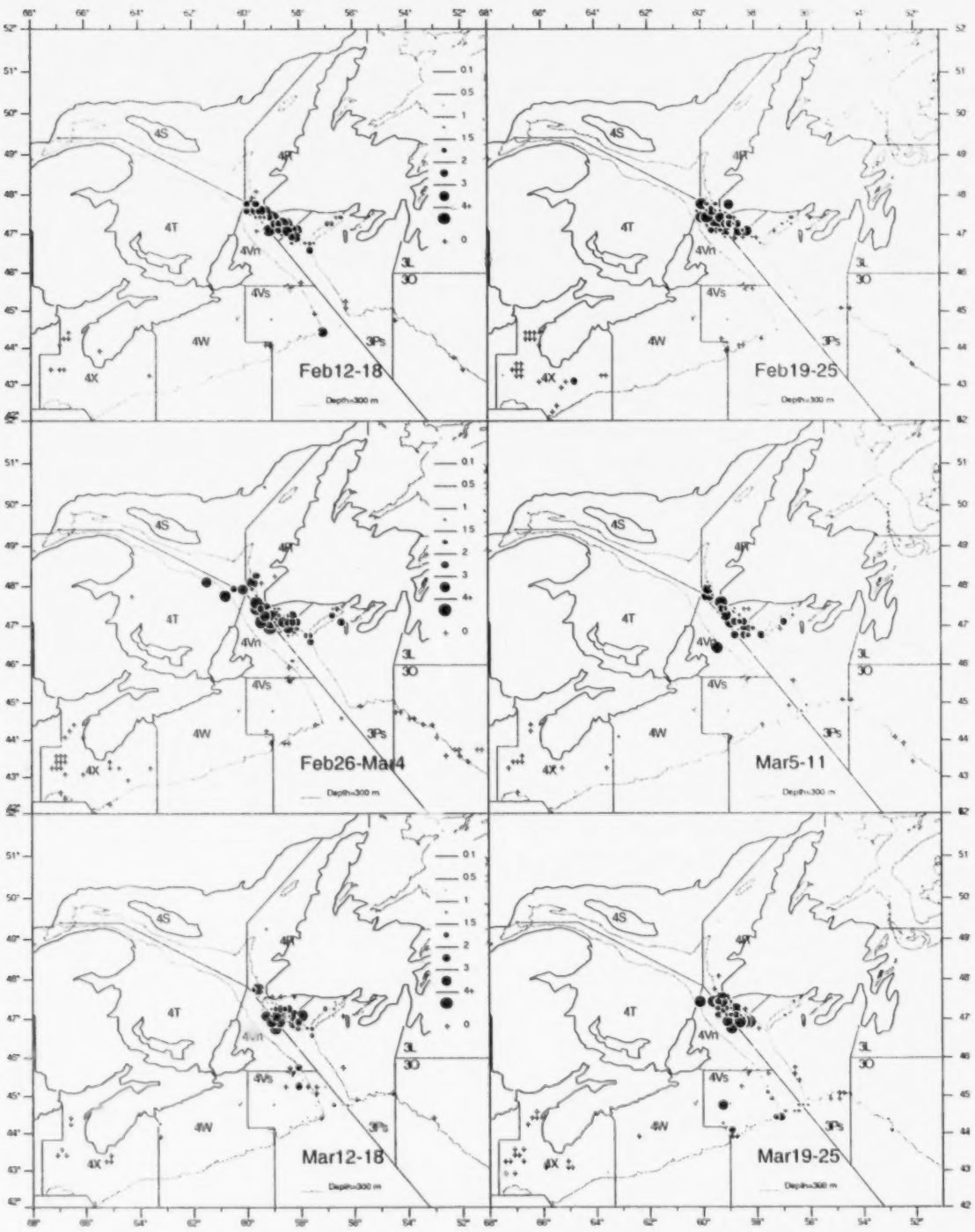

Figure 4.2. Distribution of redfish catch rates (tons/hour) based on commercial logbook information from 1988-1992 summarised by 10' squares, continued.

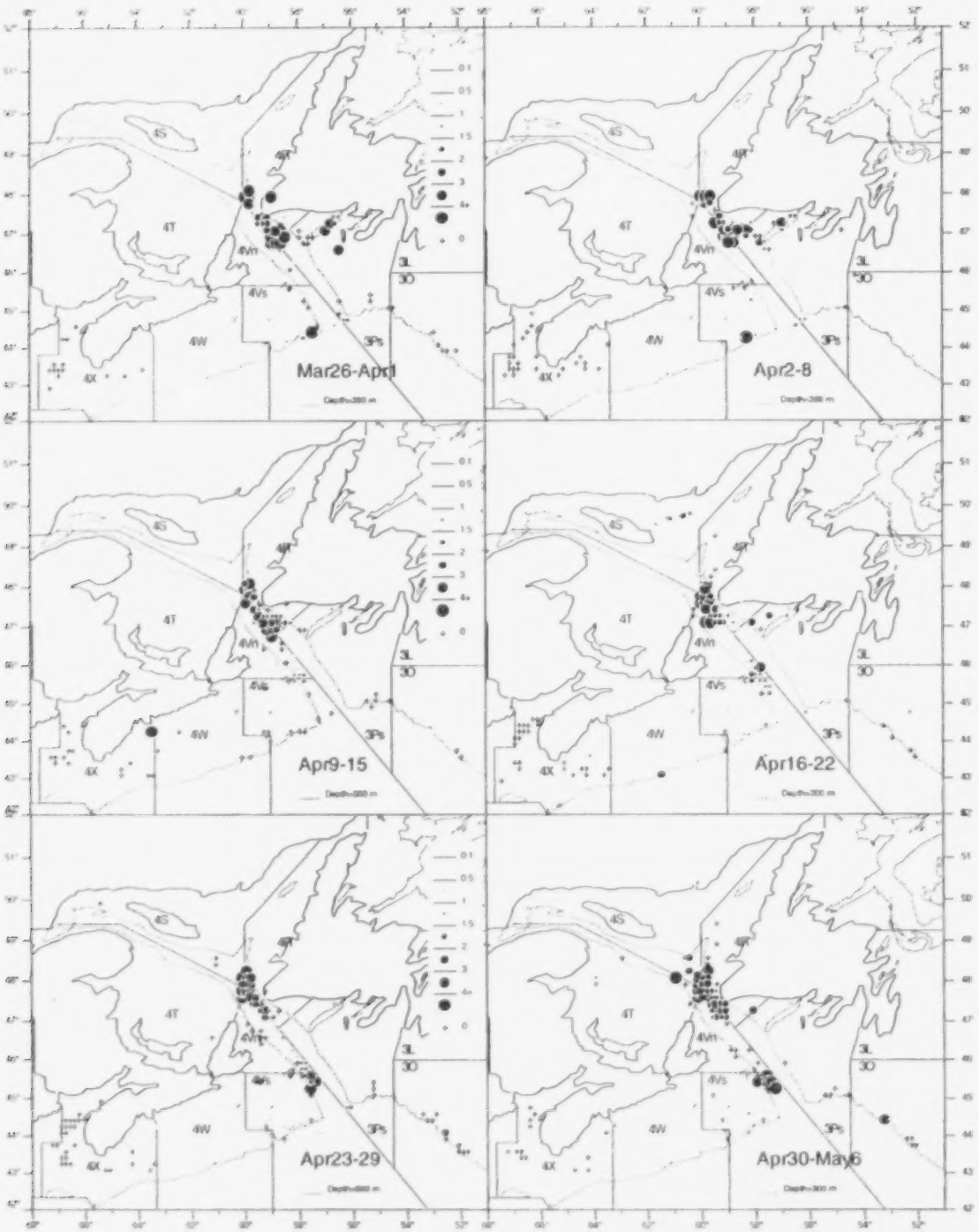

Figure 4.3. Distribution of redfish catch rates (tons/hour) based on commercial logbook information from 1988-1992 summarised by 10' squares, continued.

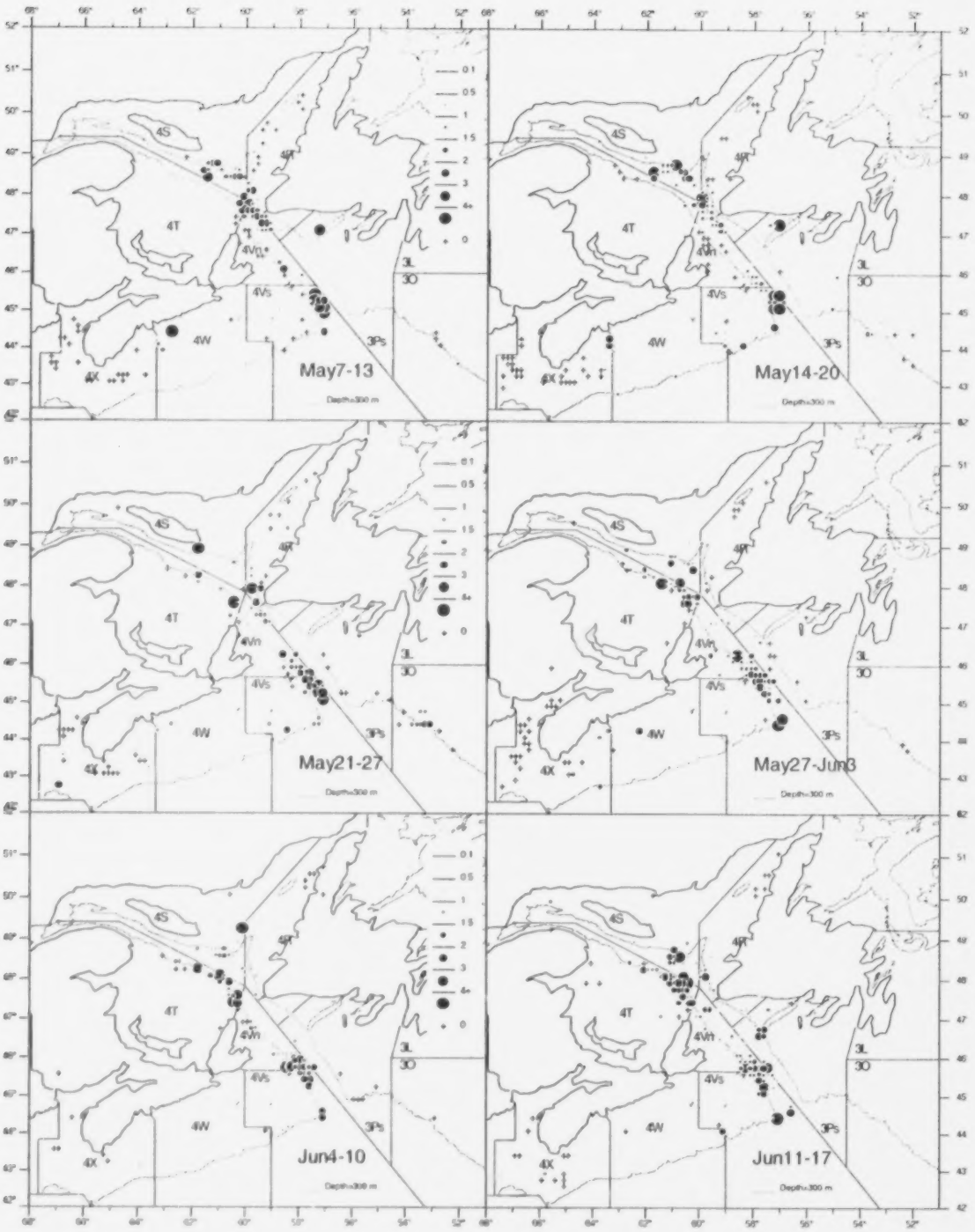

Figure 4.4. Distribution of redfish catch rates (tons/hour) based on commercial logbook information from 1988-1992 summarised by 10' squares, continued.

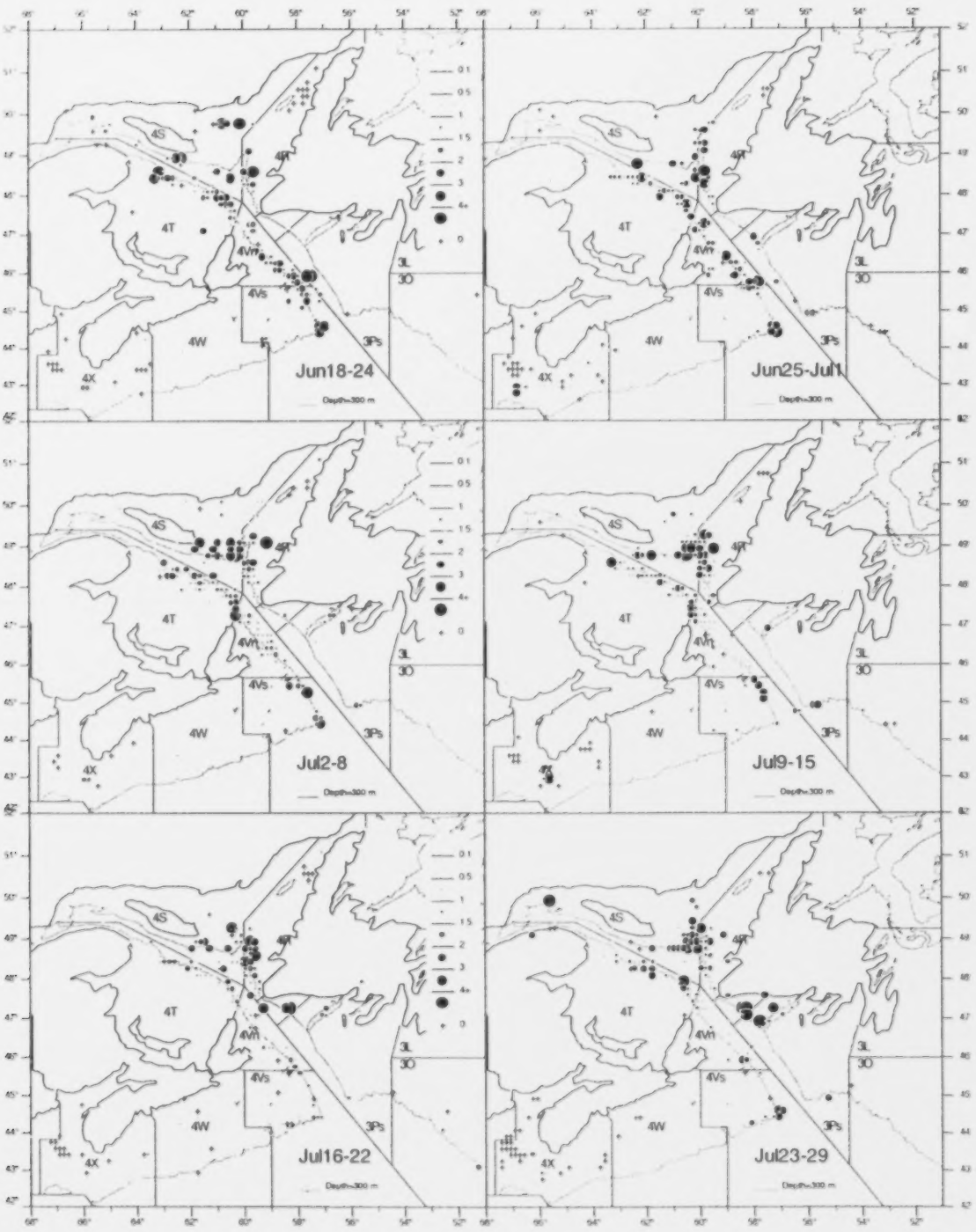

Figure 4.5. Distribution of redfish catch rates (tons/hour) based on commercial logbook information from 1988-1992 summarised by 10' squares, continued.

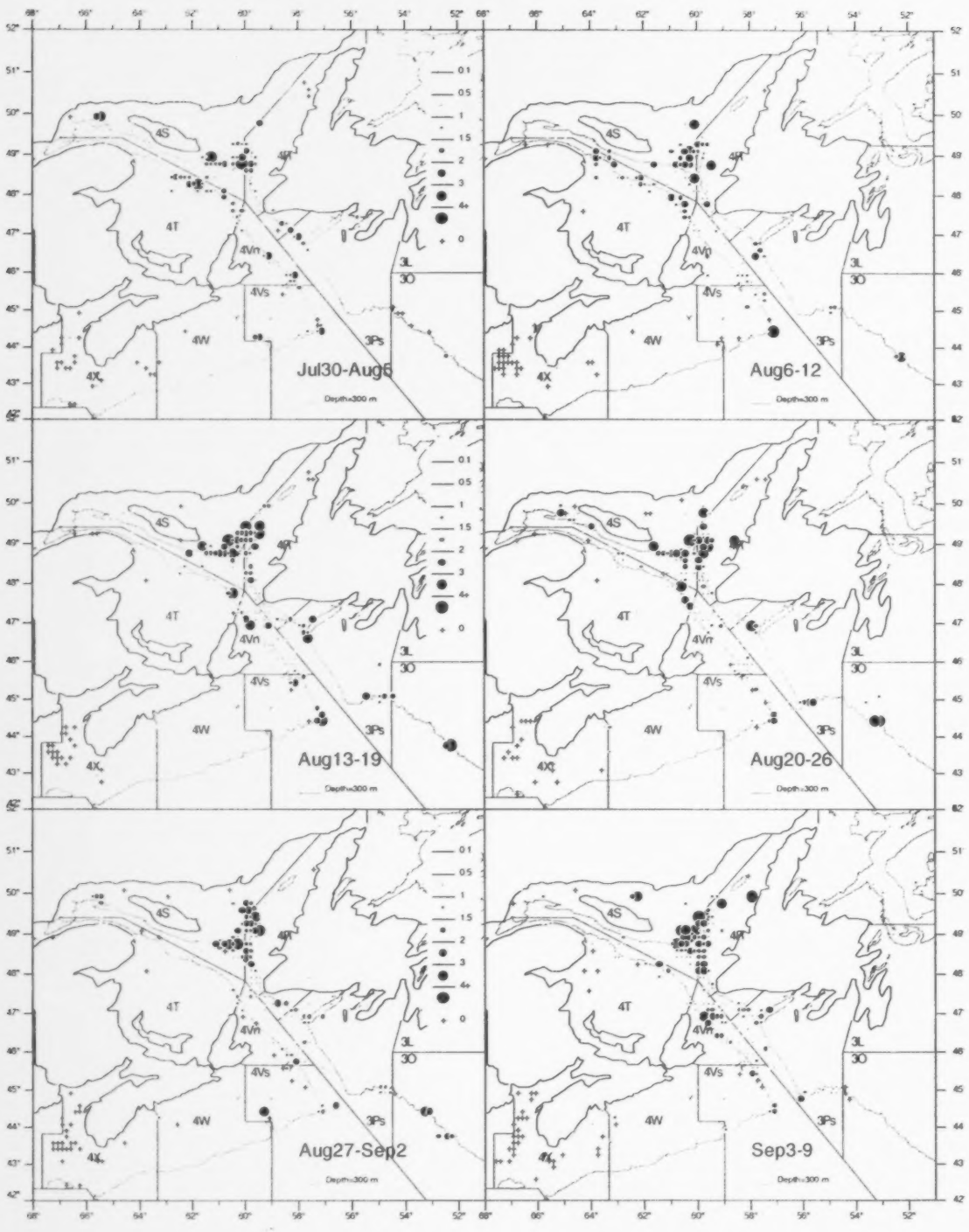

Figure 4.6. Distribution of redfish catch rates (tons/hour) based on commercial logbook information from 1988-1992 summarised by 10' squares, continued.

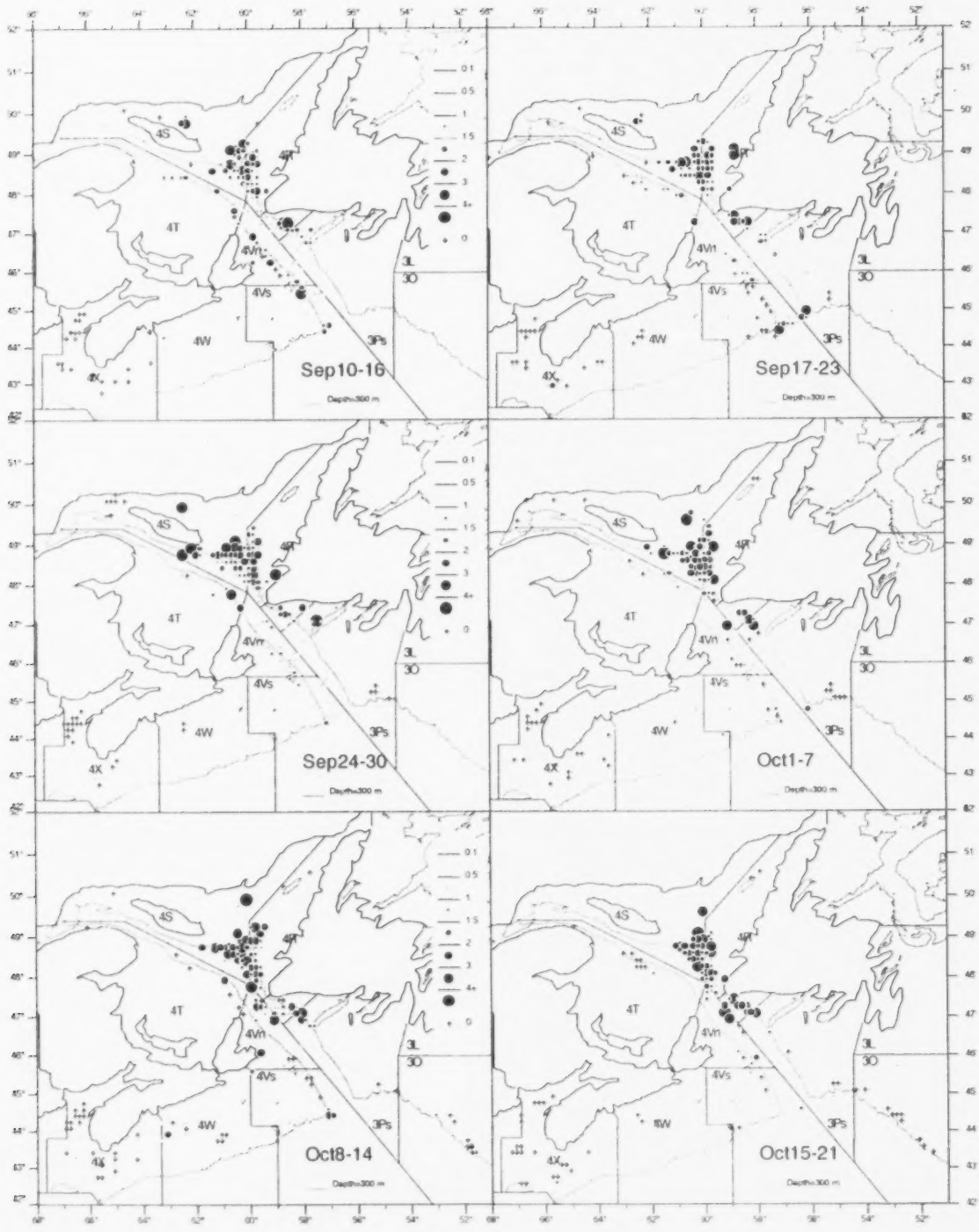

Figure 4.7. Distribution of redfish catch rates (tons/hour) based on commercial logbook information from 1988-1992 summarised by 10' squares, continued.

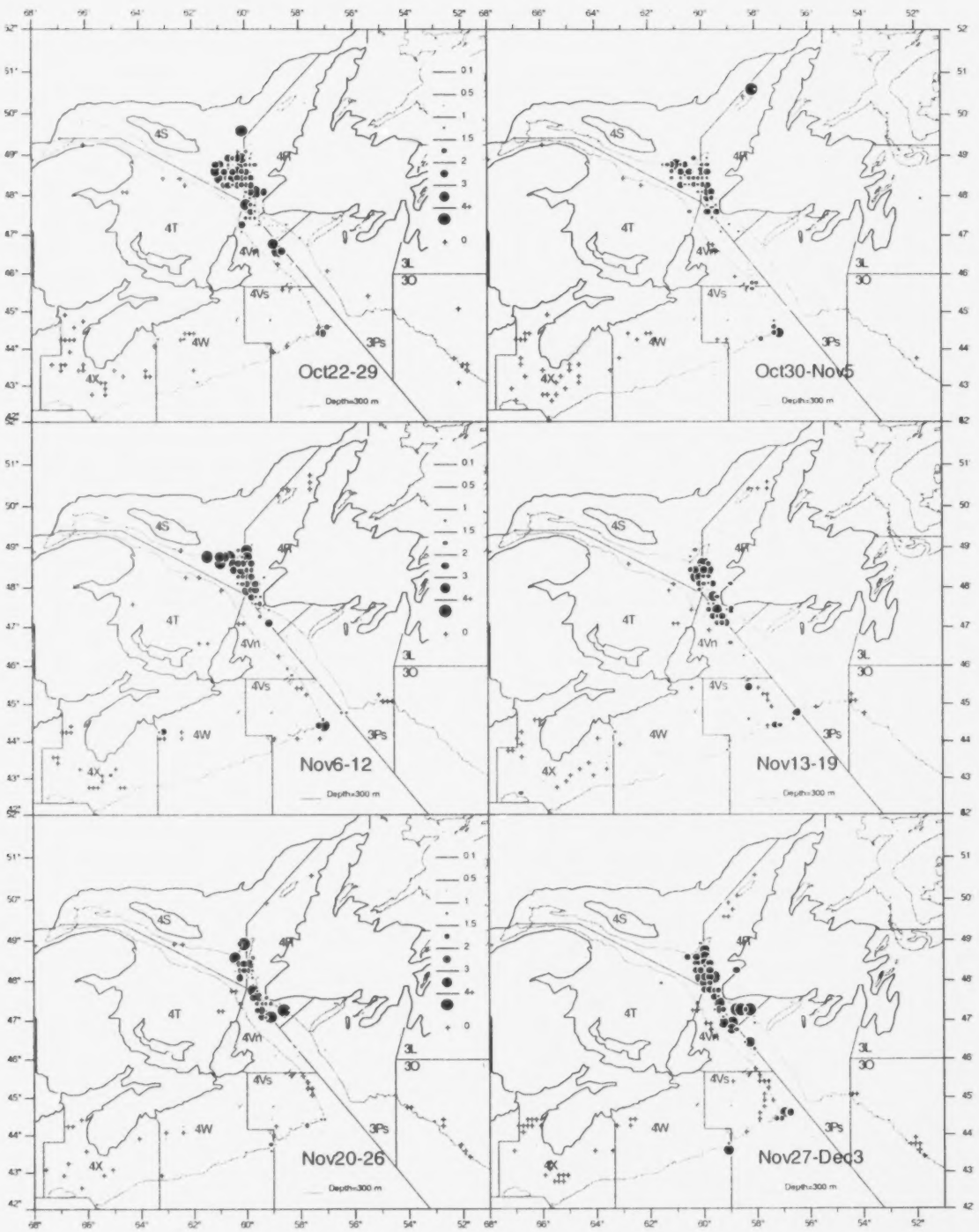

Figure 4.8. Distribution of redfish catch rates (tons/hour) based on commercial logbook information from 1988-1992 summarised by 10' squares, continued.

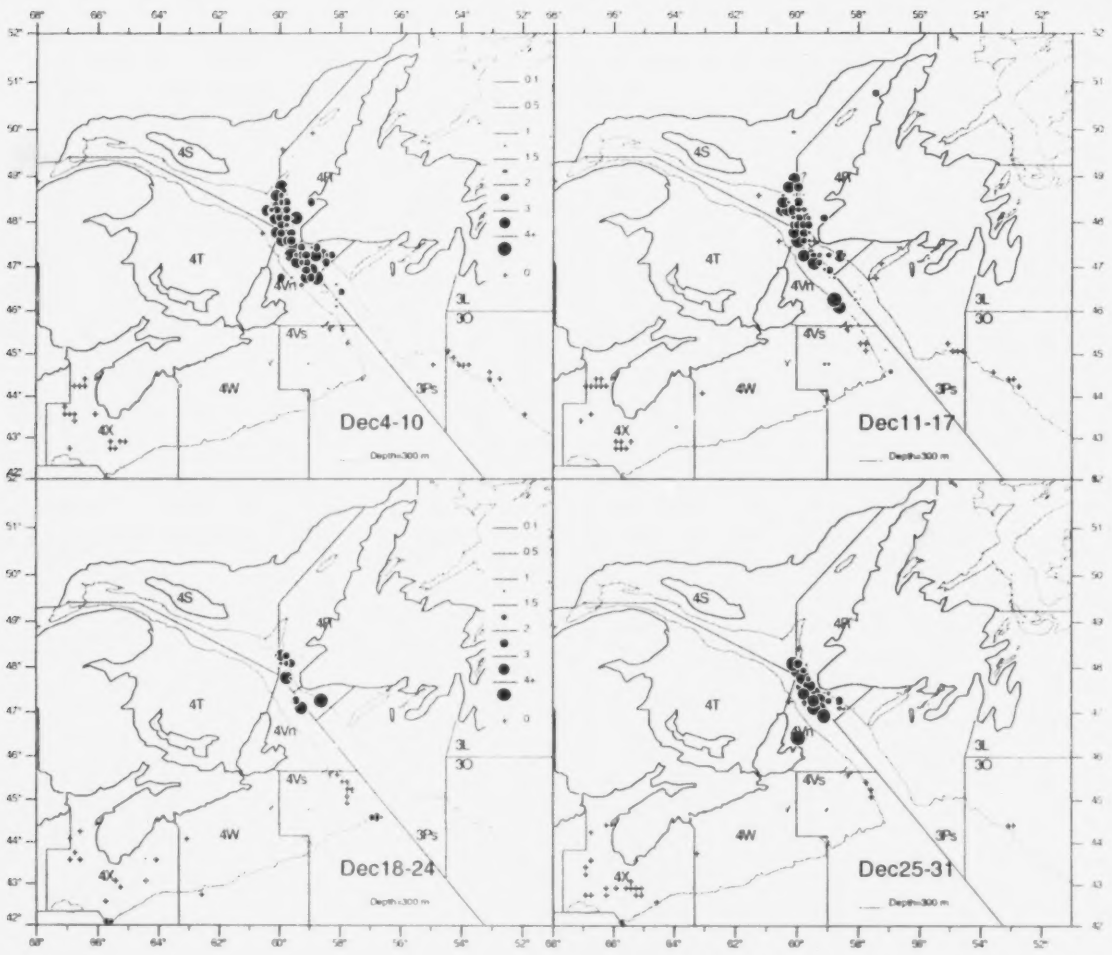

Figure 4.9. Distribution of redfish catch rates (tons/hour) based on commercial logbook information from 1988-1992 summarised by 10' squares, continued.

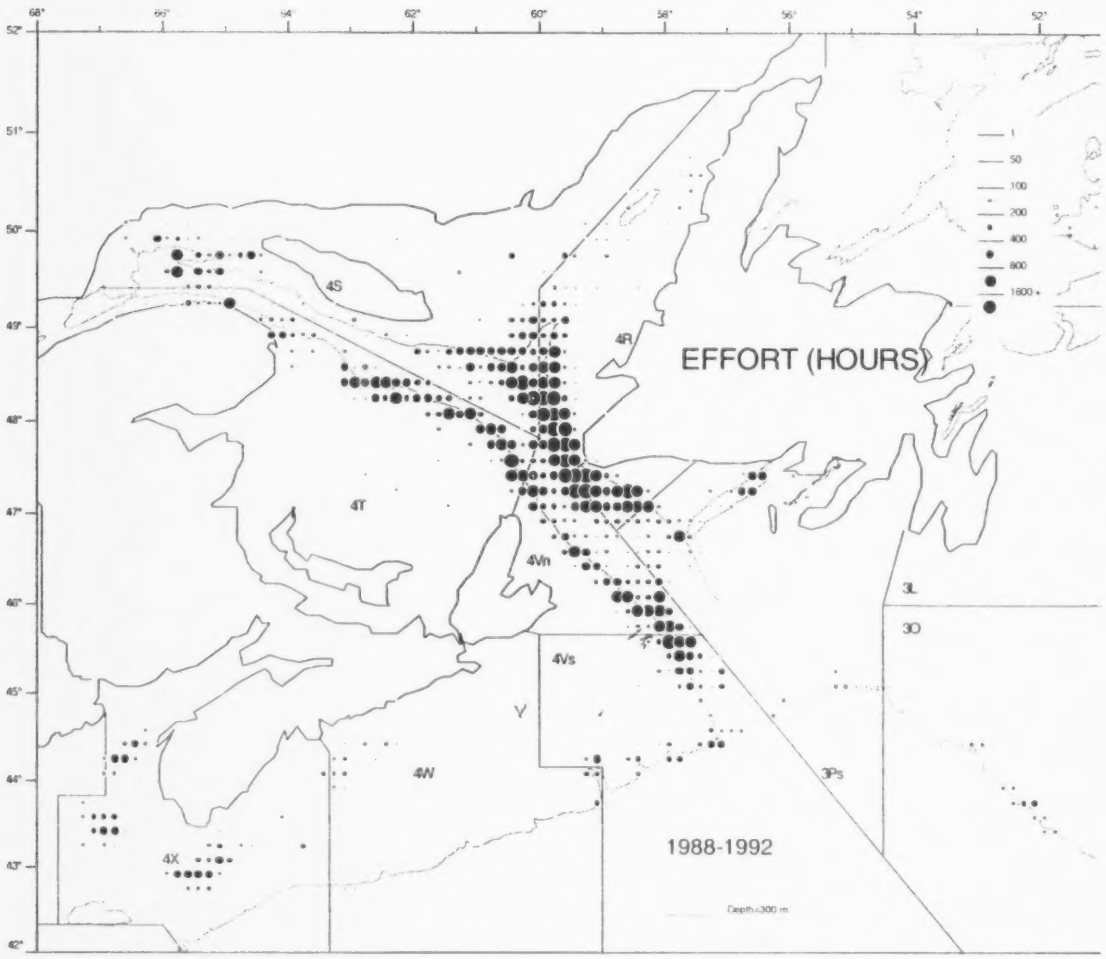

Figure 4.10. Distribution of redfish effort (hours fished) based on commercial logbook information from 1988-1992 summarised by 10' squares.

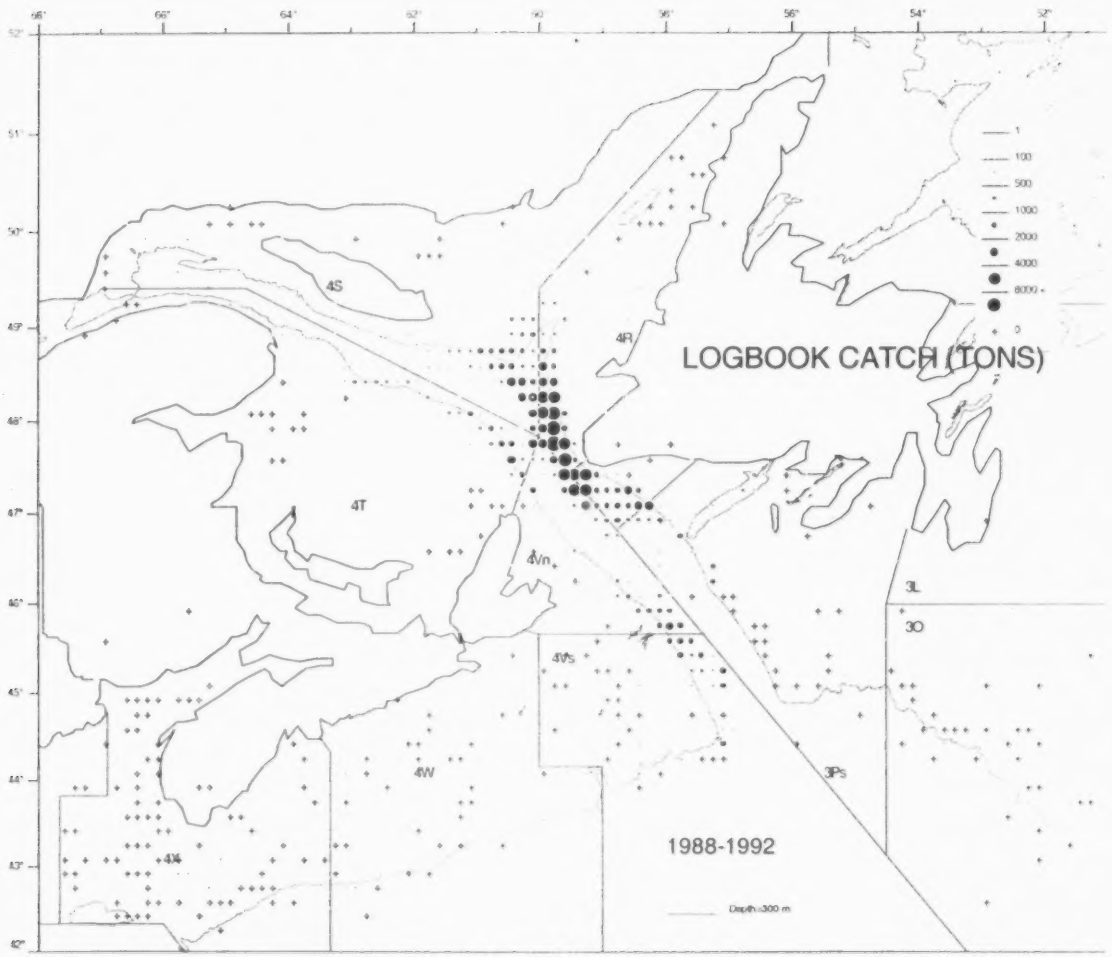

Figure 4.11. Distribution of redfish catch (tonnes) based on commercial logbook information from 1988-1992 summarised by 10' squares.

IV. DISTRIBUTION IN RELATION TO ENVIRONMENTAL CONDITIONS

5. Temperature preference and tolerance in larval and adult redfish *S. fasciatus* and *S. mentella*

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Laboratory experiments on temperature preference and tolerance of larval, juvenile and adult redfish were conducted in 1996 and 1997 using wild animals collected in the St. Lawrence estuary during SCUBA diving operations or during one of the research vessel surveys. For a full account of the surveys and material collected by our team, refer to section 9. The following is a preliminary account of some of the results from the laboratory experiments. Final conclusions should not be drawn until all samples have been examined and full statistical analyses conducted.

5.1 Temperature tolerance of larval *S. fasciatus*.

Project leader, J.-D. Dutil.

Live redfish were caught by trawl and larvae collected from gravid female *S. fasciatus* in May and June 1996 and 1997 in the Gulf of St. Lawrence. Species identification was checked by electrophoretic analysis of MDH on 50% and 100% of the females in 1996 and 1997, respectively. Those females turned out to be homozygotes. Larvae from each female were kept separately overnight at 8°C. Temperature tolerance was assessed with a standard 96 hours direct exposure survival test. The larvae were not fed during the experiment. Six temperatures were tested in the range 0-20°C. Two hundred larvae were used in 1-liter jars at each temperature with duplicates. The remaining larvae were food-deprived during 96 hours before being used in tolerance tests following the same protocol. We were unable to obtain larval *S. mentella*.

Larval *S. fasciatus* tolerated a wide range of water temperatures (Table 5.1). Mortalities were observed at all levels of temperature with fewer mortalities over four days (18%) being observed in the range 2-10°C. Mortality increased by roughly 10% in the range 10-14°C and a majority of the larvae died at higher temperatures. Some larvae survived to four days of exposure to temperatures as high as 18-20°C. Survival rates were lower in the 1996 than in the 1997 experiments and four days of food deprivation had no major impact on the outcome, particularly in 1997.

The lack of difference in the rate of mortality between newborn and starved larvae at higher temperatures suggests that increased mortalities at higher temperatures were not ascribable to energy exhaustion. We have measured the size of the oil globule and yolk sac and assayed the lipid and protein contents of the larvae from each brood used in the tolerance experiments (not shown). These results will be used to determine the energy costs of routine metabolism as a function of time and temperature.

One interesting observation was the lower survival of *S. fasciatus* larvae at very low temperatures (Figure 5.1). In 1996, higher mortalities were observed at 1.5-1.6 than at 4.2-4.3°C in food-deprived larvae. In 1997, lower temperatures (0.3-0.6°C) were achieved in the most extreme treatment and higher mortalities were observed in both newborn and food-deprived larval *S. fasciatus* (26-27%) than at 4.5°C (14%). When redfish larvae are released in late May and June, surface waters range from 4 to 10°C in the estuary and Gulf of St. Lawrence. *Sebastes fasciatus* live at shallower depths than *S. mentella*, but female *S. fasciatus* presumably release their larvae below the cold intermediate layer (CIL), which is characterised by near-zero core temperatures. Thus larval redfish must migrate through the CIL to reach the warmer surface waters. Our results suggest that the CIL may increase larval mortality significantly in the Gulf of St. Lawrence. The exact mechanism of death at lower temperatures is unknown, but one could hypothesise that larval *S. fasciatus* have also reduced physiological capacities at lower temperatures. This may impair their swimming capacity and their ability to cross the CIL particularly in those years when the CIL is colder and thicker.

Eggs and larvae of both *S. fasciatus* and *S. mentella* have also been collected in the wild and assayed for protein and lipid contents. The results from these assays have not been analysed.

5.2 Temperature preference of adult redfish

Project leader, Y. Lambert

Live redfish were caught from a series of dives in the St.-Lawrence estuary (near Les Escoumins (47°21' N 69°23' W) in October 1996, May 1997, November 1997 and November 1998. Specimens were captured with small nets by SCUBA divers in relatively shallow waters (15 to 30 m). A complete description of the diving procedures, the methods of capture, decompression and transport has been published (Larocque 2000). Essentially, two divers equipped with nets and small cages (22.5 l) were capturing the redfish during dives of 37 to 42 minutes of duration. Cages containing the redfish were left at a depth of 10 m until they were brought to the surface for transport. Periods of 24 to 48 hours at 10 m allowed fish to re-establish their buoyancy. When fish did not have enough time to decompress, their gas-bladder was deflated using a hypodermic needle. Redfish were transported to holding facilities in a 1000 l insulated tank at a temperature of 1°C using methomidate hydrochloride as a mild anaesthetic. During the different series of dives a total of 249 red-

fish were collected. With the refinement of collection procedures and husbandry conditions, few mortalities were observed for the last 2 series of dives (November 1997 and 1998). Nearly 120 redfish specimens were available for the laboratory experiments on temperature preferences of redfish. The electrophoretic analysis of the liver MDH on specimens that died during transport and the acclimation period indicated that all of them were of *S. fasciatus* species. We assumed that all live specimens were also of *S. fasciatus* species.

Redfish were kept in 7.1 m^3 circular tanks (diameter 3 m, depth 1 m) at temperatures between 4 and 6°C. Following the acclimation period (1 month), few mortalities were observed. Fish were fed to satiation 2 or 3 times a week (depending on season) with capelin and shrimp. Trials made with smaller tanks (1 m circular tanks) indicate that redfish even at low fish densities are showing signs of stress (less movement and loss of appetite) when confined into smaller volumes of water. No direct measurements of growth rates were made but the size range of the fish in tanks after 2 years of captivity indicated that the redfish were growing slowly.

Temperature preferences of redfish were determined with a horizontal thermal-gradient tank. A thermal gradient with water temperatures between 0 and 8°C was used for the experiment. Thermal sensors (23) placed at regular intervals along the tank were used to measure the temperature. Sensors were connected to a microcomputer that recorded temperatures at fixed intervals of time. Fish position in the tank was recorded with a video camera connected to a time-lapse videocassette recorder synchronised to the microcomputer.

Two series of experiments were realised. Fish were acclimated at 2°C in the first experiment and at 6°C in the second one. For each experiment, two groups of 15 fish were tested. Groups were formed according to the size of the fish. In the first group, fish length varied between 15 and 22 cm (51 to 177 g). In the second group, fish were of a larger size, length varying between 23 and 30 cm (154 to 466 g). Five fish from each size group were tested in the tank without a thermal gradient to determine if fish preferred certain parts of the tank. Ten fish from each size group were then tested independently in the thermal-gradient tank. The position of the fish was recorded at 5 minute intervals between 0-2 h, 5-7 h, 24-26 h, 28-30 h and 48-50 h.

Preliminary results are presented only for the experiment with fish acclimated at 2°C. Recordings for the experiment with fish acclimated at 6°C have not yet been analysed. All fish acclimated at 2°C that were placed in the thermal-gradient tank explored the different parts of the tank. A large proportion of the fish tested was observed at low temperatures. The mode for the frequency distributions of temperature for 75% of the fish was between 0.5 and 2°C. Frequency distributions of temperature for small fish (15 to 22 cm) did not differ from those observed for larger fish (23 to 30 cm). Moreover, no differences in the position of the fish were observed between the different periods of measurement. However, these temperatures were recorded in parts of the tank that were preferred by the

fish in the absence of a thermal gradient. Thus, we cannot determine for the moment whether temperature preferences or tank effect controls fish distributions. The analysis of the data for fish acclimated at 6°C could potentially provide information to interpret these results.

5.3 Acknowledgements

We thank F. Bélanger, F. Blouin, L. Brillant, C. Duluc, Y. Gagnon, C. Hennache, D. Leblanc, H. Lemieux, R. Miller, E. Parent, M. Péloquin, N. St-Hilaire, A. Valentin, and several other people who participated in field sampling and laboratory experiments.

Table 5.1. Cumulative mortality (M,%) of larval *S. fasciatus* over 96 hours following a direct transfer to different water temperatures (T, °C). Tolerance was tested in newborn larvae (Birth) and following a four-day period of starvation (Starved). Results for 1996 and 1997 show the average mortality for broods from 14 and 16 females, respectively.

	0-2°C		**2-6°C**		**6-10°C**		**10-14°C**		**14-18°C**		**18-20°C**	
	M	T	M	T	M	T	M	T	M	T	M	T
1996												
Birth	20	1.6	18	4.2	22	8.4	35	12.6	61	15.7	98	19.6
Starved	40	1.5	19	4.3	27	8.3	39	12.2	81	15.7	100	20.3
1997												
Birth	27	0.3	14	4.5	16	8.5	23	12.4	45	16.0	94	19.1
Starved	26	0.6	14	4.5	15	8.9	22	12.4	43	16.1	99	19.1

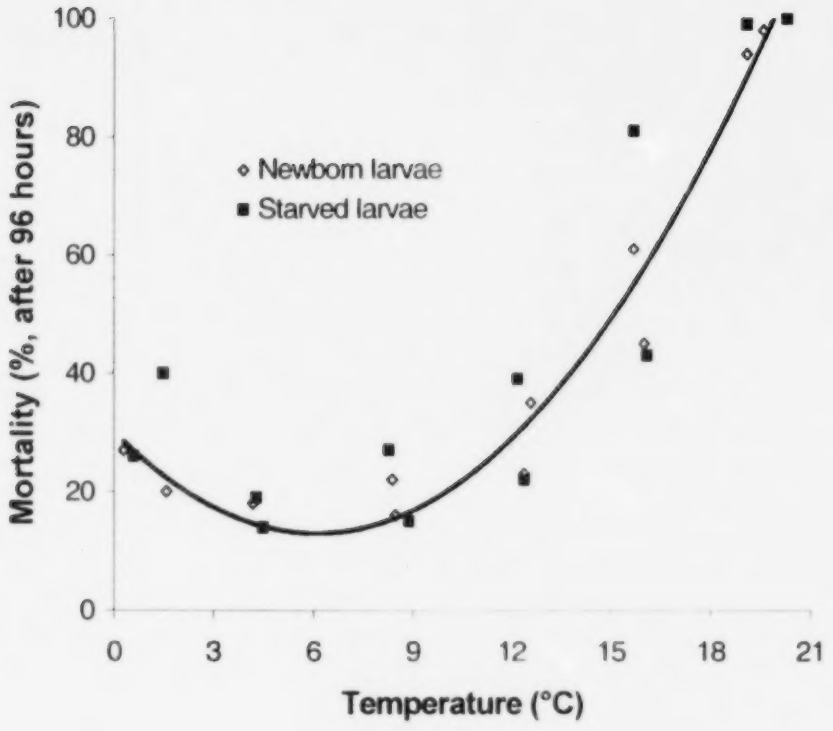

Figure 5.1. Temperature tolerance of larval *S. fasciatus* over 96 hours. Tolerance tests were conducted on new born larvae before and after a four-day period of starvation.

6. Acoustic properties of Atlantic redfish (*Sebastes* spp.)

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Redfish have large swimbladders and exhibit semi-pelagic shoaling behaviour. These features suggest that acoustic survey methods may be appropriate for these species. However, little work has been done on the acoustic properties of redfish or other *Sebastes*, in particular target strength (TS). In a attempt to create an accurate TS-length model, we measured the acoustic properties of redfish in controlled conditions and in a series of acoustic-trawl experiments. We have also documented diel vertical migration of redfish and the implications of their shoaling behaviour on acoustic assessment methods.

To conduct ex situ experiments, redfish (*Sebastes* spp.) were caught at sea with feather hooks, kept alive in sea cages for > 12 hours at 30 m depth, then transferred to cages at 10 m depth for another 12 h. Most fish survived this procedure and were in excellent condition. A total of 16 fish of length 24.5 to 30 cm were placed one at a time in an acoustically inert monofilament cage where target strength (TS) was measured for 2 hours using a 38 kHz split-beam echosounder. An underwater video camera enabled continuous monitoring of fish and cage. The best fit length based regression obtained from these data was:

$$TS = 19 \log [\text{length (cm)}] - 66.6$$

and in the standard format:

$$TS = 20 \log [\text{length (cm)}] - 68.1 \ (R^2 = 0.18).$$

TS varied by less than 4 dB over a range of tilt angles from -50° to 70° off dorsal aspect.

In addition, In situ acoustic target strength (TS) experiments were conducted in Newfoundland waters (1996-1998) using deep-tow dual beam and hull mounted split beam echosounders (38 kHz). Dual and split beam mean TS did not differ. The deep-tow system was deployed at various depths over several aggregations. Calibration corrections were

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made for depths from 5 – 70 m (< 1 dB). At ranges < 50 m from the top of the fish, TS declined, suggesting avoidance behaviour. TS was biased upward at ranges > 200 m and number of fish per sampled volume > 0.04. After controlling for variations related to range, reverberation volume and fish density, TS did not differ with respect to depth, distance from bottom, or fish sex ratio, condition factor or weight. Mean length was the dominant influence on mean TS. Pooled ex situ experimental data and in situ data (they did not differ), indicated a length based regression (weighted by SE^{-1}) in standard format:

$$TS = 20 \log [length\ (cm)] - 68.7 \quad (R^2 = 0.49)$$

for fish with mean length 14-33 cm (Figure 6.1).

Our study indicated that redfish performed regular diel vertical migrations. We measured the in situ acoustic target strength (TS) of redfish during diel vertical migration and found no effect of depth, which is inconsistent with Boyle's law. An ex situ experiment on an immobilised redfish indicated systematic changes in TS of approximately 2 dB at night when vertical migration occurs (Figure 6.2). The observed change in TS is consistent with a swimbladder volume change that would maintain redfish near neutral buoyancy throughout the range of their vertical migration. We thus propose that Atlantic redfish have an endogenous cycle in the secretion and resorption of swimbladder gas.

Redfish exhibited consistent patterns of vertical migration in winter, spring, and summer which seemed to be limited by hydrostatic pressure. The pressure at the upper range of vertical migration was never less than 67% of the pressure at the bottom. Vertical migration appeared to be a foraging strategy, in which redfish followed the migration of their euphausiid prey. On average, larger redfish were found in deeper waters, although increased variance in size distribution was observed in shallow areas. Pelagic shoals exhibited high degrees of variability in size, shape and internal structure. Attempts to explain variations in shoal density and area with various features of shoal position and structure failed. Within-shoal distance between nearest neighbouring fish did not go below 1 body length. Pelagic aggregations were generally in close proximity of dense patches of redfish along the sea floor. During the night, fish distribution was more homogenous and predictable.

Diel migration and local variance in distribution can affect the interpretation of survey results. A series of acoustic-trawl experiments was conducted on the edge of the Green and Grand Bank of Newfoundland. Redfish were on or near bottom during day and migrated vertically in the water column at night. A correction factor for the near-bottom acoustic dead zone (DZ) was developed. Total densities estimated using acoustic methods were consistently higher than densities obtained from the catch, with or without DZ corrections. The best fit of catch to acoustic densities was obtained by acoustic integration up to 5 m off bottom (corresponding to the trawl height). At this height, index of catching efficiency was near Unity for uncorrected acoustic densities. After DZ corrections were applied, the index of catching efficiency was < 1 in most cases. Uncorrected acoustic densi-

ties were significantly higher during the night than during the day. No significant day-night differences were observed after DZ corrections. Within transects of 500 pings (ca 1400 m), the CV's of areal density were on average 131% during the day and 35% at night. Consecutive passes of several transects indicated that daytime estimates were more variable then those made at night (Figure 6.3). We conclude that bottom trawling consistently underestimates redfish abundance and that acoustic estimates made at night provide the most reliable and least variable biomass estimates.

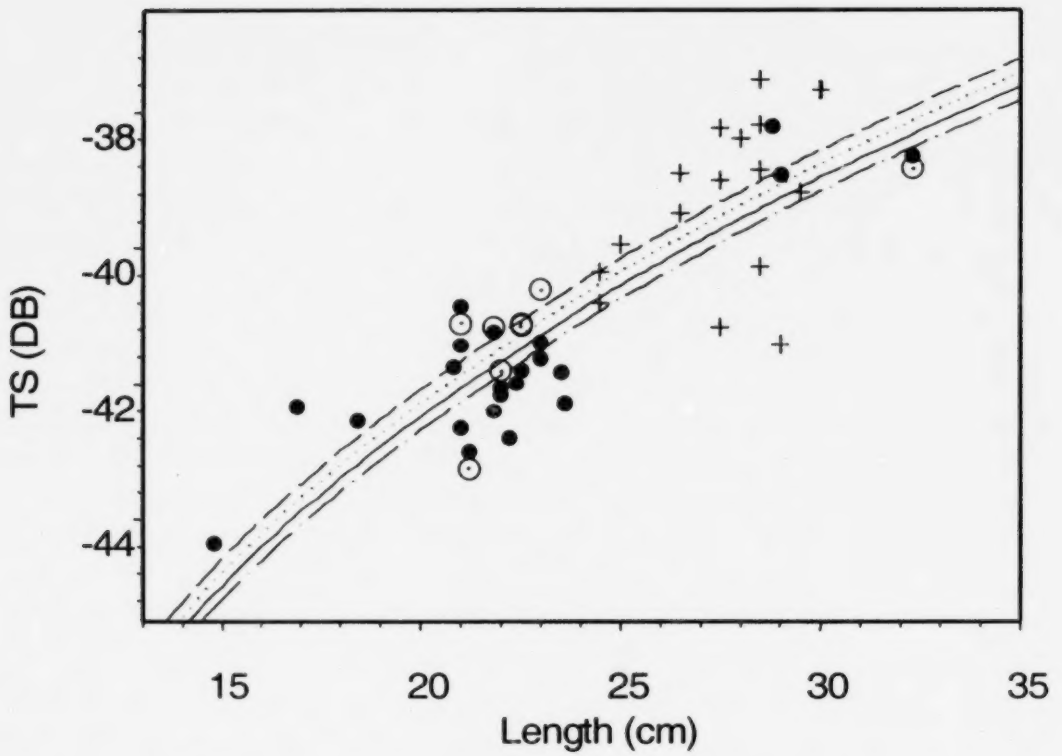

Figure 6.1. Mean target strength (dB) and mean length (cm) for redfish measured *in situ* using the split beam (closed circles) and dual beam (dotted circles) techniques. Each point represents an experiment in which $N_v < 0.04$. Crosses represent mean values for individual encaged fish measured with a split-beam system.

Unbroken line: TS (dB) = 20 log[length (cm)] –68.5 (*In situ* data only)
Broken Line: TS (dB) = 20 log[length (cm)] –68.1 (*Ex situ* data only)
Dotted line: TS (dB) = 20 log[length (cm)] –68.3 (*In situ* and *Ex situ* data)
Broken and dotted line: TS (dB) = 20 log[length (cm)] –68.7 (Weighted *In situ*† and *Ex situ* data)

† the weighted *in situ* data only has the same intercept

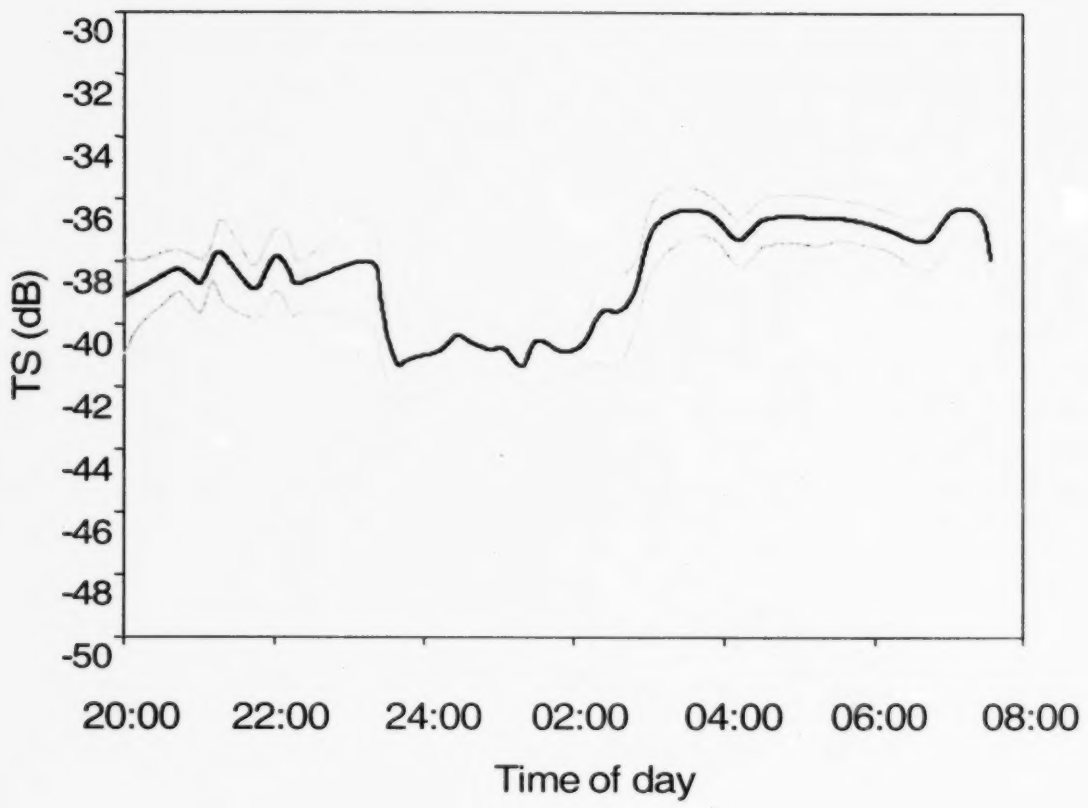

Figure 6.2. Mean target strength (TS, dB) for an Atlantic redfish immobilised in dorsal aspect at the same depth, bounded by the standard deviation. Hours of total darkness were approximately 22h00 – 5h30.

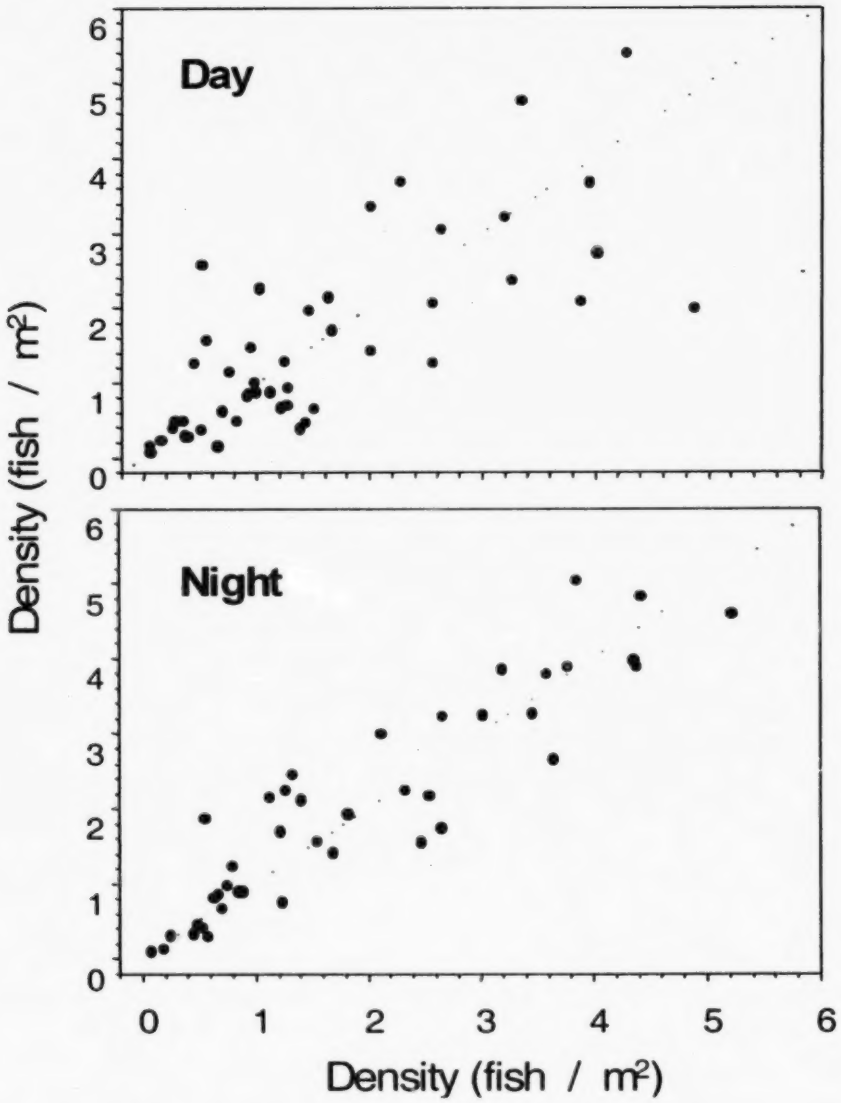

Figure 6.3. Correlation between the density (fish/m^{-2}) acoustically estimated on the first and second pass of several transects visited during the day and during the night. During the day, the coefficient of correlation between the first and second pass was 0.57 with a slope of 0.76 ($DF = 1, 46$; $F = 63.18$, $P < 0.001$). At night, the coefficient of correlation was of 0.85 with a slope of 0.92 ($DF = 1, 41$; $F = 233.48$, $P < 0.001$). Intercepts did not differ significantly from zero in either case.

7. Redfish Environmental Associations and Exposure Histories

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Motivated by recent changes in redfish distribution and migration patterns, two approaches to the interaction of redfish with the marine environment have been explored. The first is an environmental "preference" analysis, based on statistical associations between redfish catch and environmental parameters (temperature, salinity, depth). The data come from the research vessel bottom-trawl stratified random surveys in redfish Units 2 and 3 during the period 1970-95. The method, developed by Perry and Smith (1994), tests the association between fish distribution and hydrographic variables by examining the difference between the catch-weighted cumulative distribution function and that for the hydrographic variables themselves in the environment. Results for Units 2 (Figure 7.1) and 3 (Figure 7.2) indicate that redfish in both areas occupy similar depth and salinity ranges, but that the temperature range for Unit 2 redfish ($4 \leq T \leq 6^{\circ}C$) is lower than that for Unit 3 ($5 \leq T \leq 9^{\circ}C$). This may be related to differences in the dominant species (*Sebastes mentella* vs. *Sebastes fasciatus*) in the two regions.

The second approach to environmental interactions involved estimating the annual thermal exposure history for redfish in Units 1-3, based on historical temperature data and knowledge of the redfish migration routes and timing for the various stocks. Seasonal distributions of the stocks (horizontal and vertical) were determined from commercial catch records and the research vessel surveys, whereas the thermal history was derived from seasonal fields of bottom temperature, optimally interpolated to a standard grid. The results, expressed in annual degree days (Figure 7.3), show that Unit 2 redfish are exposed to the coldest conditions, followed closely by Unit 1 redfish. As with the association analysis though, Unit 3 redfish are exposed to much warmer environments. From this analysis, the maximally-probable temperatures for Units 1, 2, and 3 are (5.2, 4.8, 7.1) °C. Attempts to contrast the thermal regimes from two different time periods, for which there is evidence to suggest a difference in redfish migration patterns in Unit 1 (1970-80s vs. 1990s), shows no difference in the exposure history (Figure 7.4). No age-structured or species-specific analysis has yet been attempted.

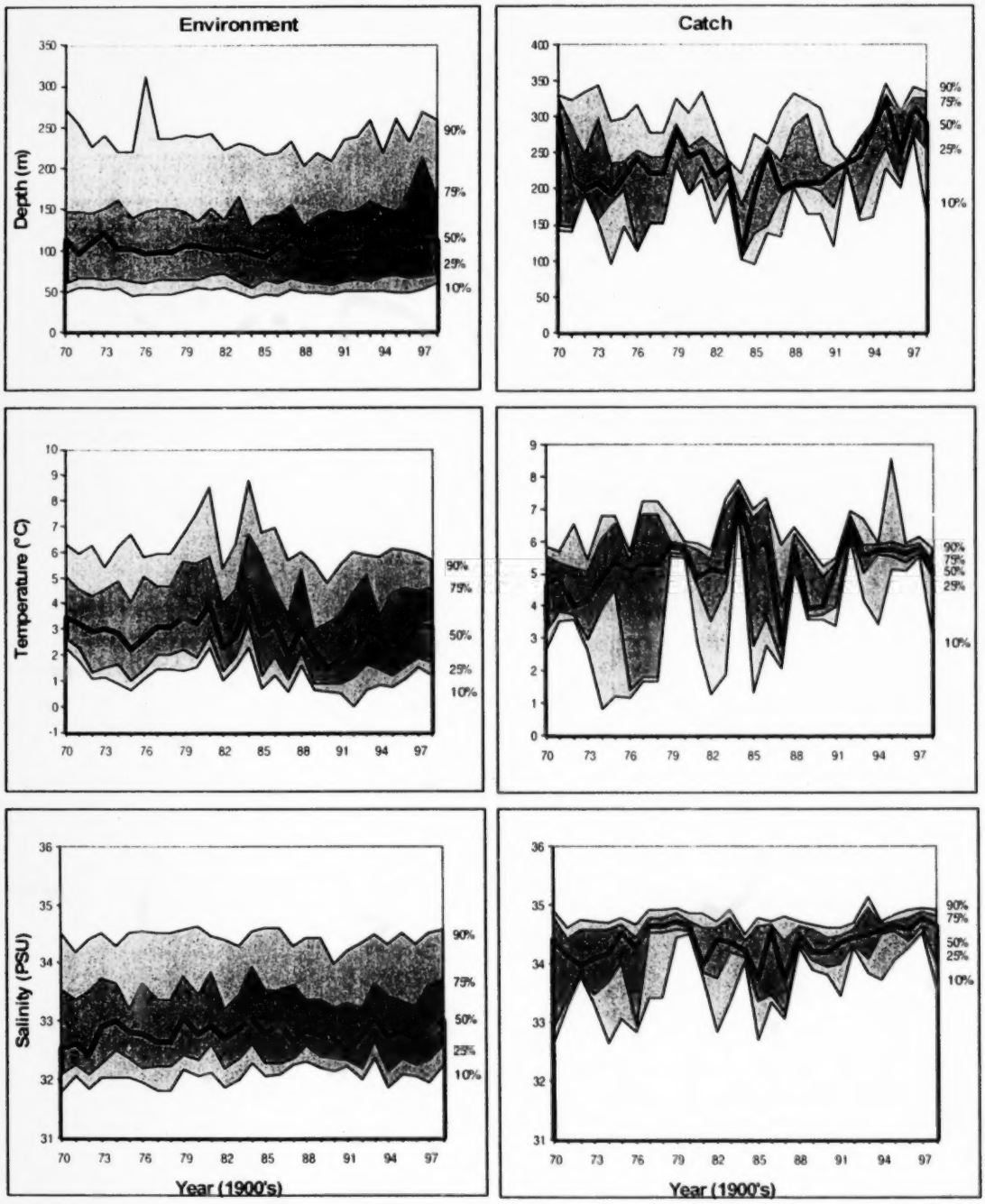

Figure 7.1. Time series of the 10, 25, 50, 75 and 90th percentiles for depth (top), temperature (middle) and salinity (bottom) within Unit 2 (Strata 440, 455/457).

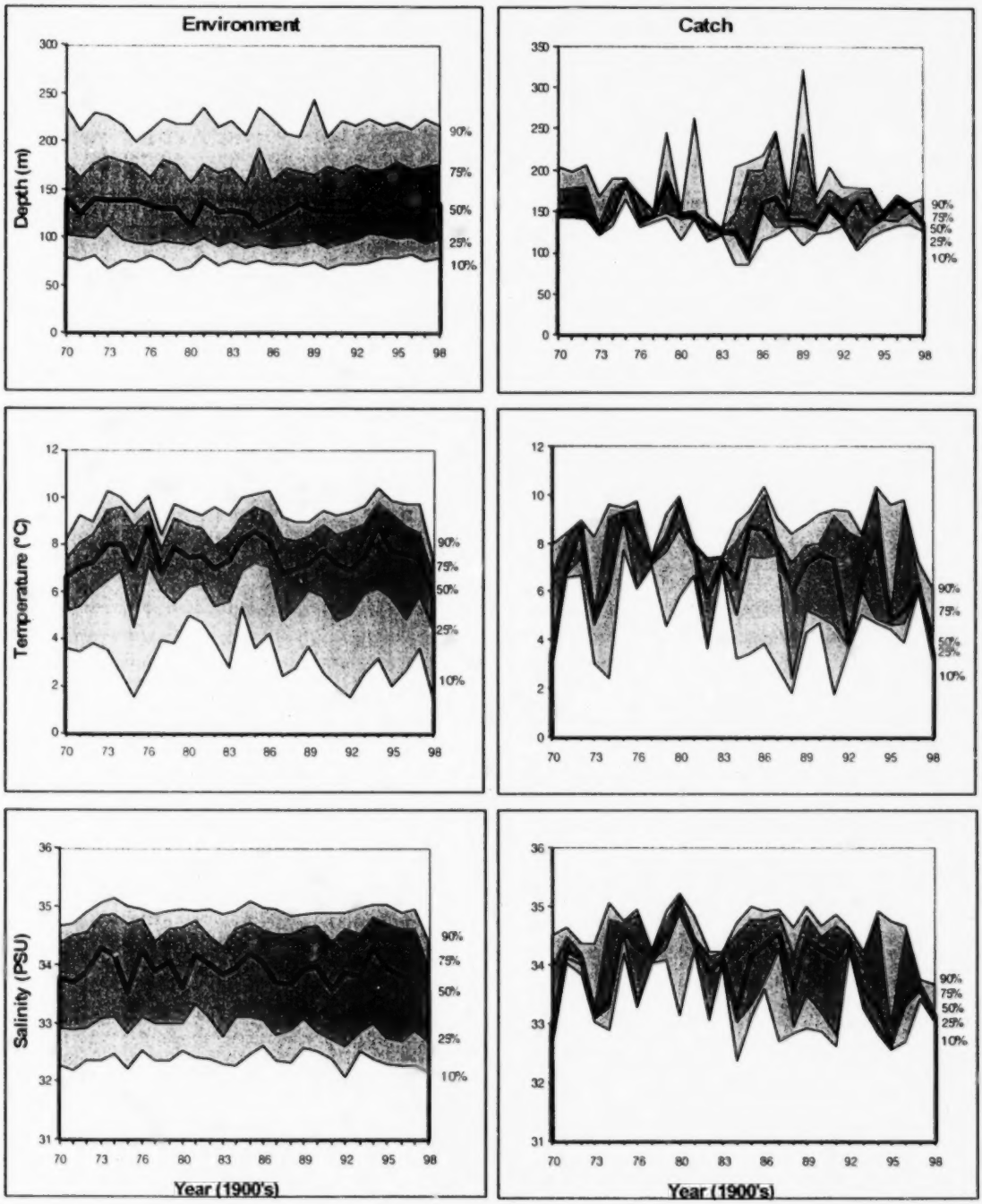

Figure 7.2. Time series of the 10, 25, 50, 75 and 90th percentiles for depth (top), temperature (middle) and salinity (bottom) within Unit 3 (Strata 456, 458/495)

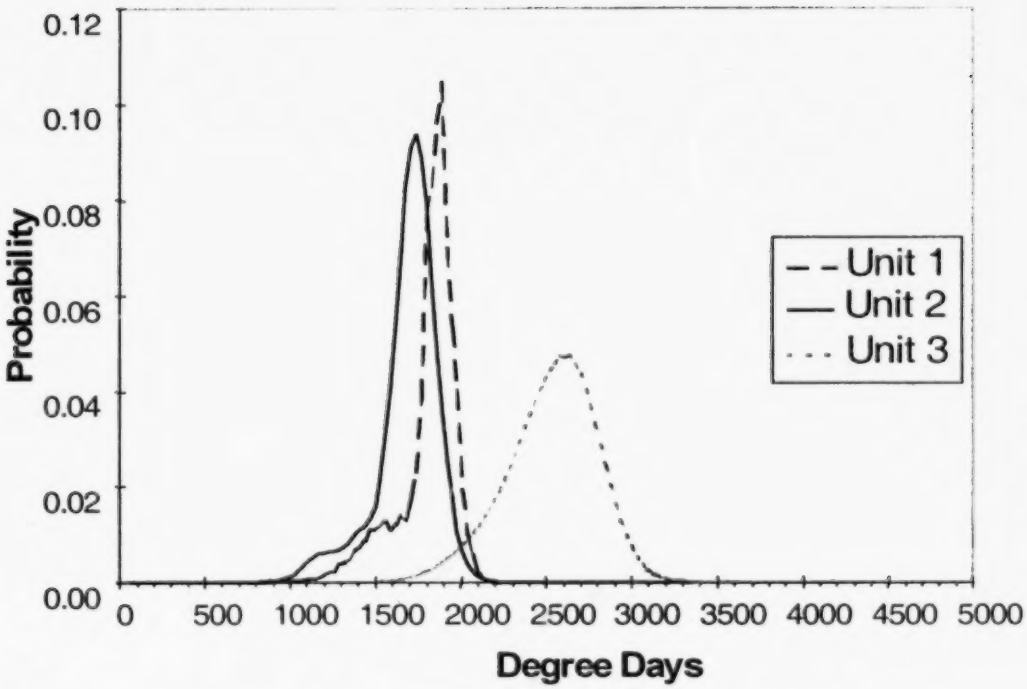

Figure 7.3. Annual degree days for redfish exposure in Units 1–3, based on full hydrographic climatology.

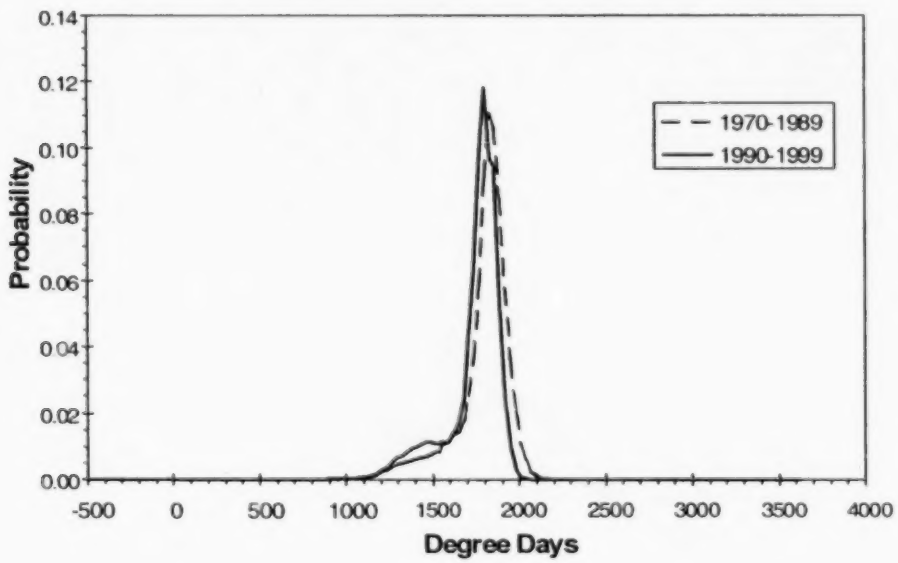

Figure 7.4 Sensitivity of annual degree-days for redfish exposure in Unit 1 for two temperature climatologies: 1970-80s vs. 1990s.

8. Distribution changes of redfish in the Gulf of St. Lawrence based on research survey data

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8.1 Introduction

Movements of Unit 1 redfish at the entrance of the Gulf of St. Lawrence during the winter have been known at least for the last 20 years (Atkinson and Power 1991). The general pattern is the southward winter migration of redfish toward Cabot Strait and the formation of concentrations in this area. Atkinson and Power (1991) reviewed the history of redfish "stock definition" in the Northwest Atlantic and described the rationale supporting the recommendation to change the southern management areas and the definition of the new Units 1, 2, and 3. These new Units were an improvement over earlier definitions. However, during recent years, changes have been observed in these movements: redfish have moved earlier and further south in the Laurentian Channel extending beyond the 3Pn/3Ps border (Morin and Bernier 1994). More recently, there has been indication that the southerly movement may start as early as September. The reasons for these changes in recent years are not known and need to be examined.

The objective of this study was to describe the depth, temperature and latitudinal redfish (juveniles and adults) distribution in summer and winter in the Gulf of St. Lawrence using research survey data.

8.2 Materials and methods

Redfish catch data were analysed from the 4 series of research vessel trawl surveys (Table 8.1) carried out by the Department of Fisheries and Oceans in the northern Gulf of St. Lawrence and Cabot Strait (NAFO Divisions 3Pn4RST):

For all surveys, we compared (for all, juveniles [< 20 cm] and adults [≥ 20 cm]) distributions of sampled and occupied (i.e. sampled weighted by abundance expressed as number of fish caught) temperatures, depths, and latitudes among years. For every year, we plotted the 2.5, 50, and 97.5% values of sampled and occupied cumulative distribution

functions of temperatures, depths and latitudes. See Perry and Smith (1994) and Castonguay *et al.* (1999) for a complete description of the methods.

8.3 Results and discussion

Table 8.2 summarises the distribution observed in the summer-early fall in the Gulf of St. Lawrence for 3 periods. Although no changes were observed in the range of temperatures occupied, redfish (all sizes) were found deeper in the late 1990's than the 1980's and 1970's. Also, the redfish distribution shifted to the south in the late 1990's. Juveniles were found in a wider range of temperatures (1 to 6°C) than the adults (3 to 6°C).

For the winter, no significant change in the temperature occupied was observed and redfish (all sizes) were found deeper (350-400 m) in the 1990's than in the 1980's (250-350 m). Also, the redfish distribution shifted to the south in the early 1990's, this change was more important for adults than for juveniles.

The reasons for these changes are still being investigated. The same analyses on 3Pn4RS cod showed that a deeper and more southerly shift was also observed in winter during the same period. A significant correlation was calculated between cod latitude in winter and the temperature of the cold intermediate layer (CIL) of the previous summer. This suggested that cod responded to the cooling of the CIL by changing their migration patterns. Since redfish are generally found deeper than the CIL, an influence of the CIL on their distribution seems less likely.

Table 8.1. List of surveys used in the analysis

	Season	Vessel	Years
1	Winter (January)	Gadus Atlantica	1978-1994
2	Summer (August)	Lady Hammond	1984-1989
3	Summer (August)	Alfred Needler	1990-1998
4	Fall (September and October)	AT Cameron	1977-1980

See Castonguay *et al.* (1999) for a description of the first 3 surveys series. The last survey (A.T. Cameron) was conducted by the Newfoundland Region at the end of the 1970's.

Table 8.2. Mean of medians of redfish distributions (depth, temperature and latitude) in summer/early fall for three periods in the Gulf of St. Lawrence.

Periods	Depth (m)	Temperature (°C)	Latitude
1977-1980	247	5.6	49.1
1986-1989	266	5.7	49.3
1995-1998	277	5.3	48.6

V. RECRUITMENT STUDIES

9. Shrimp fishery bycatches of redfish and review of the possible causes of the disappearance of the 1988 year-class

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9.1 Introduction

In the Gulf of St. Lawrence, strong recruitment has been intermittent, occurring every 6-12 years. There has been strong year classes in 1946, 1956, 1958, 1971 and 1980. Also, year-classes that were present in very large numbers at age 2 to 4 (based on research survey data) were not found in subsequent years and never contributed significantly to the fishery. These year-classes were in 1966, 1974 and 1988 (Sandeman 1973, Parsons and Parsons 1976; Morin et al. 1999). For example, the estimate for the 1988 year-class in 1991 was 2.2×10^9 (2.2 billion), but by 1994, the estimate had dropped to 48×10^6 (48 millions) (Figure 9.1; Morin et al. 1999). The factors responsible for the disappearance of these small immature redfish are unknown. The most likely explanation was migration, but no data suggests that the 1988 year-class moved out of the Gulf (Anon. 1995). Other factors that may have contributed to these disappearance were reviewed during this study. These factors are the fishing mortality due to by-catches of the shrimp fishery and the natural mortality due to poor environmental conditions or predation.

The objective of this project was thus to review the possible causes of the disappearance of the 1988 year-class at the beginning of the 1990's. Analyses on the by-catches of the shrimp fishery during this period were performed (Figure 9.1).

9.2 Shrimp fishery bycatches of redfish

9.2.1 Material and methods

Redfish bycatch data were extracted from the Gulf Observer database for the 1990 to 1993 period. For each fishing area, the monthly ratios of redfish to shrimp catches were calculated and applied to each monthly tonnage of landed shrimp to estimate the monthly tonnage of redfish, including discarded redfish.The number of fish was estimated using a length-weight relationship (Morin and Bernier, 1992). Finally, the percentages of discarded redfish, as calculated from the catch and discard weights noted by the Observers,

were applied to the estimated monthly tonnage of redfish to assess the discarded redfish contribution to the total monthly tonnage. All the monthly redfish length frequencies were then combined in order to obtain the yearly length frequencies.

9.2.2 Results

Table 1 summarised the redfish discard information form the shrimp fishery in the Gulf. The highest amount of discards was observed in 1991 but the total abundance of fish < 25 cm would account only for a small part of these discards. The proportion is high in 1992 and is probably explained by the important decrease of the 1988 year-class. With the introduction of the Nordmore grid in the shrimp fishery in 1993, the amount of discards dropped sharply (Table 9.1).

Similar results were obtained by Atkinson (1984) in the Esquiman Channel at the beginning of the 1980's : Discards of redfish represented about 1 % of small redfish population in the area sampled. It was concluded that : " A rather insignificant proportion of the juvenile redfish population in the north-eastern part of the Gulf was destroyed during the course of the shrimp fishery off Port-aux-Choix in 1976-80 period ". Thus, the rapide decline of the 1974 year-class was probably due possibly to emigration from the region, as they became older.

9.3 Discussion

The 1990's were unusually cold for the 30-100 m depth layer (DFO, 2000). However, we don't know how these observations may have affected redfish because of the deep layer distribution of this species. Also, no significant changes in the temperatures occupied were observed between 1990 and 1993 at depths (200-300 m) where juveniles are mainly found (Castonguay and Morin, unpublished data). The median temperature was between 4 and 5°C.

Consumption of prey by harp seals in Atlantic Canada was estimated for the period 1990-1996, by bringing together information on individual energy requirements, population size, distribution and diet composition (Hammill and Stenson, 2000). Harp seal diet composition for this period, showed that redfish was an important component (Hammill and Stenson, 2000). However, the most recent harp seal diet information has shown that redfish were rarely found in stomachs (Hammill, per. com.).

This review did not bring any new explanations for the disappearance of the 1998 year-class. The seals consumption would be the most plausible cause. However, a comparison to the 1974 year-class disappearance showed that seal consumption was probably low during that period and that year-class was very abundant. Also, the 1980 year-class, which is the last strong year-class that sustained the fishery at the end 1980's and beginning of the 1990's did not disappear at the beginning of the 1980. This year-class was probably composed of fish of *S. mentella* whereas the 1988 year-class was *S. fasciatus* (Sévigny and de

Lafontaine, 1992; Sévigny et al. 2000). Thus, it is possible that *S. fasciatus* recruitment in the population is not sustainable or disappears in the Gulf of St. Lawrence for reasons that remain unclear.

Table 9.1. Results of the redfish discards estimations of the shrimp fishery. The abundance of the < 25 cm on the DFO summer survey is indicated.

Année	Alfred Needler Abundance (10^6)	Discards (10^6)	% Discards
1990	1 504	11,2	0,7
1991	2 197	43,1	1,9
1992	427	26,2	6,1
1993	107	0,4	0,4

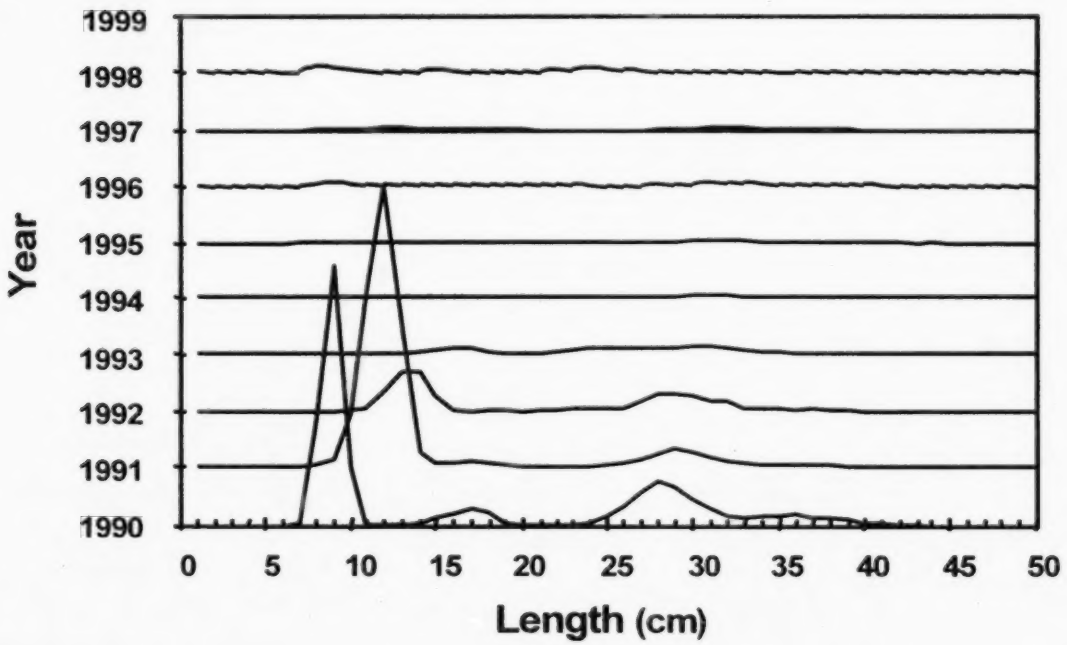

Figure 9.1. Redfish length frequencies observed during the DFO summer survey in 4RST. The 1988 year-class is the large peak observed in 1990 and 1991.

10. Variability in reproductive characteristics and larvae production of redfish (*Sebastes fasciatus*) in the Gulf of St. Lawrence

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Samples were obtained from 15 surveys and sampling trips (Table 10.1) in 1996, 1997, 1998 and 1999. Ten of those took place in the spring and early summer period with a major focus on larval production in the Gulf of St. Lawrence. Female and male reproductive cycles were also examined in the summer and autumn (6 sampling trips including collections from the Labrador Sea, Teleost surveys) and in January (WT Templeman survey). The areal coverage in the Gulf was most extensive during the January 1997 (WT Templeman), late-April 1997 (Teleost), August 1996 (Alfred Needler) and November 1998 (Richmond Odyssey) research surveys (Figure 10.1). Some 11,368 redfish have been measured, weighed, dissected and sampled for species identification using genotypic and meristic criteria, and for a description of diet composition, physiological condition, fecundity, and timing of maturation, mating and embryonic development. This translated into well over 100,000 samples, digitalized images and histological slides. This material was secured for later analyses. The following is a preliminary account of some of the results. Final conclusions should not be drawn until all samples have been examined and statistical analyses conducted. Part of this material is presented as Chapter 5 of this report (page 73).

10.1 Variability in reproductive characteristics and larvae production of redfish in the Gulf of St.-Lawrence.

Project leader, Y. Lambert

The main objective of this project was to assess inter-female variability in the production of larvae and to determine if this variability was related to differences between individuals in the available energy reserves. The underlying hypothesis was that variability in environmental conditions leading to differences in accumulated energy reserves between individual female redfish would result in differences in potential fecundity, fertilisation rate, number of developing embryos and number of larvae released. The original plan was to follow the seasonal changes in the energy reserves and reproductive state of female redfish (*S. fasciatus* and *S. mentella*) in the Gulf of St. Lawrence between 1996 and 1998.

Regular sampling over the year was used to follow the changes in the energetic condition and reproductive characteristics of the females during maturation and reproduction.

The specific objectives of this study were to determine how energy reserves are distributed in the different tissues of redfish, to evaluate seasonal and inter-individual variations in condition and energy reserves of redfish, to measure the fecundity and energy investment in the gonads and to examine relationships between female characteristics (length and energy reserves) and reproductive characteristics (energy investment, fecundity, number of embryos and larvae).

The results presented in this report should be considered as preliminary since compilation, validation and statistical analysis of all data is not completed. Only data on some of the reproductive characteristics of female redfish during the spring period are presented.

10.1.2 Materials and methods

Fish collected in each sample were analysed for fork length, total weight, carcass weight (gutted weight), and the number of soft rays in the anal fin. Liver, gonad, and digestive tract weights were also taken. Sex and maturity were determined. Gonad samples were taken to determine fecundity, egg/larval energy content and proportion of non-viable larvae. Fecundity was determined using a gravimetric method. One of the two gonads stored in 4% formaldehyde was rinsed and cleaned to liberate eggs or larvae. All eggs/larvae and two sub-samples of 100 eggs/larvae were weighted. The ratio of total weight on mean weight of sub-samples was used to estimate fecundity. The proportion of non-viable larvae was determined in a sub-sample of 200 larvae. Larvae with a white and opaque yolk sac were classified as non-viable. Egg/larvae sub-samples were frozen in order to determine individual energy content.

A sub-sample of muscle taken under the first dorsal fin, a sub-sample of the gonads, the liver, the digestive tract and the carcass were also analysed for dry weight and energy content. The digestive tract and the carcass were homogenised in a meat grinder before the analyses. Analyses for each tissue were done in duplicate except for the carcass where they were done in triplicate. Water content was determined by drying tissue samples to constant weight at 65°C and energy content was determined by combusting tissue samples in an oxygen bomb calorimeter (Parr, model 1261). Numbers of samples are shown in Table 10.2.

A first classification of fish as *Sebastes mentella* or *S. fasciatus* was done at sea using the number of soft rays in the anal fin. The final classification of each specimen was done in the laboratory using electrophoretic analysis of the liver malate dehydrogenase (MDH) (Payne and Ni 1982; McGlade *et al.* 1983).

10.1.3 Preliminary results

Of all fish sampled between 1996 and 1999, 1361 were analysed for length, total weight, weight of liver, digestive tract, gonad, and carcass. Dry weight and energy content of the different tissues of these fish were also determined. The number of samples analysed is presented in Table 10.2. The results of these analyses are not presented as compilation, validation and statistical analyses are not completed.

The electrophoretic analysis of the liver MDH was done on each specimen to determine the species. Redfish with the genotype MDH*A1A1 were classified as *S. mentella*, those with genotype MDH*A1A2 as heterozygotes between *S. mentella* and *S. fasciatus* and those with MDH*A2A2 as *S. fasciatus*.

Weight-length relationship of reproductive females

For the females of both species, the lowest size at maturity was around 23-24 cm. The size range of reproductive females during the 1996-1999 period was much shorter in *S. fasciatus* than in *S. mentella*. While reproductive females of *S. mentella* were in the range of 24 to 47 cm, very few females of *S. fasciatus* exceeded 35 cm in length.

Close relationships between somatic weight and length were observed for each species. High coefficients of determination ($R^2 = 0.97$) were observed for reproductive females of each species sampled in the northern Gulf of St. Lawrence in April 1997 (Table 10.3). Despite small differences in somatic weight, reproductive females of *S. fasciatus* were significantly (ANCOVA $P < 0.004$) heavier than females of *S. mentella* and female heterozygotes. Somatic weight at length did not differ between female *S. mentella* and female heterozygotes ($P > 0.47$).

Stable relationships between somatic weight and length were observed for reproductive females of *S. fasciatus* in the St. Lawrence estuary between 1997 and 1999 (Table 10.4). Analysis of covariance on log transformed data did not reveal any differences between samples of reproductive females obtained in the months of May and June in 1997, 1998, and 1999.

Fecundity

Gravid female redfish sampled in the spring of 1997 to 1999 in the St. Lawrence estuary (NAFO Division 4T) and in the northern Gulf of St. Lawrence (NAFO Division 4R and subdivision 3Pn) were used to examine the variability in the production of larvae between females, the production of larvae of each species in the same area and the interannual variability in the production of larvae.

Absolute fecundity ranged from 3 330 to 107 000 larvae per female and increased with female size. Power functions were used to describe the relationship between fecundity and female size for each species. All relationships were significant ($P < 0.001$) with exponents varying between 3.45 and 5.1. Significant differences in the fecundity length relationships for each species were observed in April 1997 in the NAFO area 3Pn4R (Figure

10.2). Analysis of covariance on log transformed data revealed that female *S. fasciatus* (MDH*A2A2) had a significantly greater fecundity than female heterozygotes (MDH*A1A2) and female *S. mentella* (MDH*A1A1). However, no significant differences ($P > 0.59$) were observed between female heterozygotes and female *S. mentella*.

Inter-annual variability in absolute fecundity of *S. fasciatus* in the St. Lawrence estuary (NAFO area 4T) was examined for the period between 1997 and 1999. No significant differences (ANCOVA, $P > 0.16$) were detected between the three years (Figure 10.3). However, a large variability in absolute fecundity was observed. Coefficients of determination for the fecundity-length relationship of each year varied between 0.37 and 0.84. The restricted size range of the females can partly explain this observation. Nevertheless, the absolute fecundity of a 30 cm female varied between 11 000 and 45 000 larvae.

The presence of non-viable larvae characterised by a white and opaque yolk sac was observed in many reproductive females. Non-viable larvae were mainly observed in females at the pre-extrusion (maturity stage 9) and extrusion (maturity stage 10) stages of maturity. The mean proportion of non-viable larvae in reproductive females of *S. mentella* in April 1997 was close to 20% with proportions varying from 0% to 60%. The analysis of these data is not yet completed and the reasons for the observation of these non-viable larvae are still unclear. However, the absolute fecundity of the females could be significantly affected by the presence of these non-viable larvae.

10.1.4 Preliminary conclusions

Although preliminary, the results of this study indicate differences in the reproductive characteristics of female redfish in the Gulf of St. Lawrence. Significant differences were observed between females of *S. fasciatus* and females of *S. mentella*. Weight-length relationships and fecundity at length differed between *S. fasciatus* and *S. mentella* captured in the same area in April 1997. Females of *S. fasciatus* were heavier at length and had a greater fecundity (number of larvae) than *S. mentella*. Heterozygote females of *S. mentella* and *S. fasciatus* had the same characteristics as females of *S. mentella*.

Inter-annual comparisons did not reveal significant differences in the weight-length relationship and fecundity at length between reproductive females of *S. fasciatus* captured in the St. Lawrence estuary during the months of May and June between 1997 and 1999. The fecundity at length observed for *S. mentella* in 1997 is higher than the fecundity at length reported by St-Pierre and de Lafontaine (1995) for *S. mentella* in the same area in 1989-1990. The fecundity estimate for a 35 cm female reported in their study was 18 656 compared to 33 655 in our study.

Further treatment of the data is necessary to complete the analyses of the samples and to confirm the preliminary results presented here. Nevertheless, the results suggest that larval production in the Gulf of St. Lawrence could significantly vary between species and between years.

10.2 Timing of sexual maturation, mating, breeding and spawning in *S. fasciatus* and *S. mentella*.

Project leader, J.-D. Dutil.

Maturity stage was determined by macroscopic examination of the gonads in fresh specimens according to Ni and Templeman (1985) for males and St-Pierre and de Lafontaine (1995) for females in 1997, 1998 and 1999. Samples of the gonads were collected in 1996 and 1997 (1300 fish), fixed in 10% buffered formalin, dehydrated in ethanol and embedded in paraffin. Sections (6-8 μm) were stained with haematoxylin and eosin and examined under a microscope. These slides will be examined in view of determining size at first maturation, peak maturation period in males and females, and breeding and fertilisation periods in both *S. fasciatus* and *S. mentella*. In 1997, fertilised eggs and larvae of 365 mature females were also digitalized. Those images have been examined to assess female size effects on the size and schedule of embryonic development in the period from late-April to late-June in both *S. fasciatus* and *S. mentella*. Finally, the eggs and larvae of mature females have been sampled and stored in a freezer (-78°C) and their lipid and protein contents determined.

Questions which may be answered looking at those data include: 1. Are *S. fasciatus* and *S. mentella* larvae released synchronously? 2. Do *S. fasciatus* and *S. mentella* larvae differ in size at extrusion? 3. Do *S. fasciatus* and *S. mentella* reach sexual maturation at the same size? How does fish size affect maturation and larval characteristics? When do males reach maturity in the fall and when does mating actually occur? When does fertilisation takes place relative to mating? The areal and temporal coverage of the mating and breeding events may be sketchy, but major progress is expected relative to the current level of biological information on redfish, particularly in the Gulf of St. Lawrence. The following is a very partial account of the information available; most of the data have not been analysed.

Macroscopic examinations of the gonads suggested that *S. fasciatus* and *S. mentella* differ in the timing of embryonic development and larval extrusion in the Gulf of St. Lawrence (Figure 10.4). In late-April 1997, a majority of female *S. mentella* were classified as being in the pre-extrusion (stage 8) or extrusion (stage 9) stages with less than 10% of mature females being at an earlier stage. Heterozygote females followed the same pattern exactly. In contrast, female *S. fasciatus* were in stage 8 and stage 9 (42 and 39% of the individuals), respectively. In the St. Lawrence estuary, larval extrusion mainly took place in early June (Figure 10.5). Modal stage of maturity was stage 8 in 1999 (sampling May 17-23), stage 9 in 1998 (sampling May 28-June 3), and stage 10 in 1997 (June 6-12).

Based on digitalized images of the eggs and larvae, embryonic development was also found to be more advanced in *S. mentella* and heterozygotes than in *S. fasciatus* in late-April 1997 (Table 10.5). Species identification was based on MDH score. *S. fasciatus* eggs were in general spherical in shape whereas *S. mentella* and heterozygotes eggs were elliptical (> 80%). The maximum egg diameter was larger in *S. mentella* and heterozygotes

but yolk sac and oil globule diameters were similar. More embryos had reached stage 5, i.e. were fully developed with melanophores present on the body in *S. mentella* (49%) and heterozygotes (68%) than in *S. fasciatus* (30%). Fewer eggs had hatched in the ovaries of *S. fasciatus* and the proportion of females with hatched larvae in the ovary was smaller in *S. fasciatus* than in *S. mentella* and heterozygotes. Because the shape of the eggs differed, differences in maximum egg diameter may not have indicated a difference in the size of the embryos. Thus we measured the surface area of 10 eggs (as viewed in a digitalized 2-dimensional image) in a sub-sample of 10 female *S. fasciatus* and 10 female *S. mentella*. Surface area averaged 1.27±0.40 mm^2 in *S. fasciatus* and 2.24±0.58 mm^2 in *S. mentella* suggesting that larvae are smaller at birth in *S. fasciatus* than in *S. mentella*.

The development of oocytes in female redfish starts in the spring period and is completed in the fall season. Maturing females sampled in August (NGCC Alfred Needler survey) had started to accumulate vitellogenin in their oocytes but they were not fully mature. In early November (Richmond Odyssey samples), oocytes were mature. Half of the females sampled had spermatozoa in their ovaries indicating that mating was in progress. The Richmond Odyssey samples were exclusively *S. mentella* and heterozygotes. Mature inseminated female redfish were found in both the Gulf of St. Lawrence (Unit 1) and south of Newfoundland (Unit 2) indicating that mating takes place in both management Units in *S. mentella* and heterozygotes (Figure 10.6). The male samples have not been analysed but a preliminary examination of the winter samples (NGCC W.T. Templeman survey) suggests that mating is over in early January as the vast majority of the testes were in the spent condition.

10.3 Respective diets of *S. fasciatus* and *S. mentella*.

J.-D. Dutil, D. Chabot, R. Miller and Y. Lambert

Stomachs which contained food remains have been collected and preys identified. Most redfish regurgitate their stomach contents as a result of gas bladder inflation when retrieved from great depths. The following is an account of the frequency of occurrence of prey items identified in 600 fish with intact stomachs in 1996 and 1997 in the Gulf of St. Lawrence. Some regurgitation may have taken place even when the stomach is intact, but the relative proportion of prey items in the stomachs, and the proportion of stomachs containing specific prey items, should both be representative. Prey items were identified to species when possible, but have been lumped into larger taxa in Table 10.5 and in Figure 10.7 and Figure 10.8. The results have been broken down according to species, based on MDH score (homozygotes exclusively), size categories, and season (spring: April to June; summer: July to September).

The vast majority of beaked redfish in our sample had crustaceans in their stomach both in spring (98.6%) and in summer (94.9%) with fish present in only 14.6 and 10.8% of the stomachs examined in spring and summer, respectively. When samples for spring and

summer were combined, 97.5 and 13.5% of the stomachs had crustaceans and fish, respectively.

Fish size had an impact on diet with a greater proportion of smaller redfish having small-sized crustaceans in their stomachs and a greater proportion of larger redfish having large-sized crustaceans in their stomachs. Fish were found in large-sized redfish only (Table 10.5).

The overlap in the diet of *S. mentella* and *S. fasciatus* was great (Figure 10.7). When we restrict our analysis to a common range of sizes, the two species appear to rely on the same food resources (Figure 10.8).

10.4 Acknowledgements

We thank F. Bélanger, F. Blouin, L. Brillant, C. Duluc, Y. Gagnon, C. Hennache, D. Leblanc, H. Lemieux, R. Miller, E. Parent, M. Péloquin, N. St-Hilaire, A. Valentin, and several other people who participated in field sampling and laboratory experiments.

Table 10.1. Research surveys and sampling trips conducted in 1996, 1997, 1998 and 1999 as part of the research program on redfish in the Northwest Atlantic. **A)** Monthly schedule: letters indicate month and numbers refer to **B)** Ship, trip number and sampling dates.

A

	J	F	M	A	M	J	J	A	S	O	N	D
1996				1	2,3,4	4,5	6	7	7			
1997	8			9		10						
1998					11					12,13	14	
1999					15							

B

Number in A	Ship	Trip	Start	End
1	Calanus II	IML96-010	22.04.96	25.04.96
2	A. Hort	Rimouski	13.05.96	14.05.96
3	Calanus II	IML96-015	24.05.96	27.05.96
4	Calanus II	IML96-019	27.05.96	29.06.96
5	Posseidon	Lunenberg	19.06.96	19.06.96
6	Needler	Halifax	15.07.96	15.07.96
7	Needler	AN248	08.08.96	01.09.96
8	Templeman	T-201	06.01.97	26.01.97
9	Teleost	IML97-007	20.04.97	29.04.97
10	Calanus II	IML97-018	04.06.97	20.06.97
11	Calanus II	IML98-018	25.05.98	05.06.98
12	Teleost	98-71	01.10.98	08.10.98
13	Teleost	98-72	10.10.98	22.10.98
14	R. Odyssey	RO2	29.10.98	11.11.98
15	Calanus II	IML99-013	19.05.99	23.05.99

Table 10.2. Number of samples for the different tissues analysed for dry weight and energy content between 1996 and 1999.

Tissue	1996	1997	1998	1999
Muscle				
Dry weight	656	507	117	81
Energy content	178	135	117	
Liver				
Dry weight	604	516	117	81
Energy content	215	115	117	
Gonads				
Dry weight	417	462	116	81
Energy content	140	132	103	
Digestive tract				
Dry weight	624	515	117	81
Energy content	122	181	117	
Carcass				
Dry weight	450	148		
Energy content	50	122		

Table 10.3. Relationship between somatic weight and length for reproductive female redfish sampled in April 1997 in the northern Gulf of St. Lawrence.

Species	**a**	**b**	**R^2**	**n**
S. mentella	8.6×10^{-6}	3.076	0.98	61
Heterozygote	8.2×10^{-6}	3.087	0.96	19
S. fasciatus	9.0×10^{-6}	3.083	0.98	33

Table 10.4. Relationship between somatic weight and length for reproductive female of *S. fasciatus* sampled in the St. Lawrence estuary during the month of May between 1997 and 1999.

Year	**a**	**b**	**R^2**	**n**
1997	1.43×10^{-5}	3.002	0.98	25
1998	2.57×10^{-5}	2.897	0.83	70
1999	3.45×10^{-5}	2.843	0.95	81

Table 10.5. Developmental stage and size of eggs in *S. mentella*, *S. fasciatus*, and heterozygotes based on MDH score. Samples were collected and examined during the Teleost cruise in late-April 1997. Sizes of the egg capsule, yolk sac and oil globule represent maximum diameters. The developmental stage of unhatched embryos is shown as a proportion with stage 2 representing embryos in the morula, blastula or gastrula stage, stage 3 formed unpigmented embryos, stage 4 formed pigmented embryos with melanophores restricted to the eyes and stage 5 formed pigmented embryos with melanophores extending over the body. Proportion of hatched eggs and proportion of mature females with hatched eggs are shown as percentages. Egg shape is shown as a ratio of the proportions of spherical and elliptical eggs.

	Size of eggs and energy stores			**Embryonic development**				**Hatched eggs**	**Females with larvae**	**Shape of egg**
	Egg capsule	**Yolk sac**	**Oil globule**	**Stage 2**	**Stage 3**	**Stage 4**	**Stage 5**			
S. mentella	2.186±0.387	1.000±0.083	0.526±0.050	0.0	2.7	47.9	49.3	16	73	19:81
Heterozygote	2.241±0.310	1.000±0.065	0.515±0.046	0.0	3.6	28.6	67.9	14	82	7:93
S. fasciatus	1.754±0.406	0.990±0.133	0.514±0.062	2.7	24.3	43.2	29.7	5	47	61:39

Table 10.6 Proportion (%) of redfish in various size categories having different prey items in their stomachs. Stomachs with unidentified crustaceans and fish remains were excluded.

Prey item	Fish size (mm)						
	< 80	80-111	112-146	147-199	200-299	300-399	400-499
Copepods	11	51	28	23	4	7	0
Amphipods	11	27	0	21	6	15	0
Mysids	11	0	38	40	42	34	35
Euphausids	0	11	3	28	28	18	0
Shrimps	0	3	7	10	24	50	70
Soft pout	0	0	0	0	1	15	10
Capelin	0	0	0	0	0	1	10
Barracudina	0	0	0	0	0	1	0

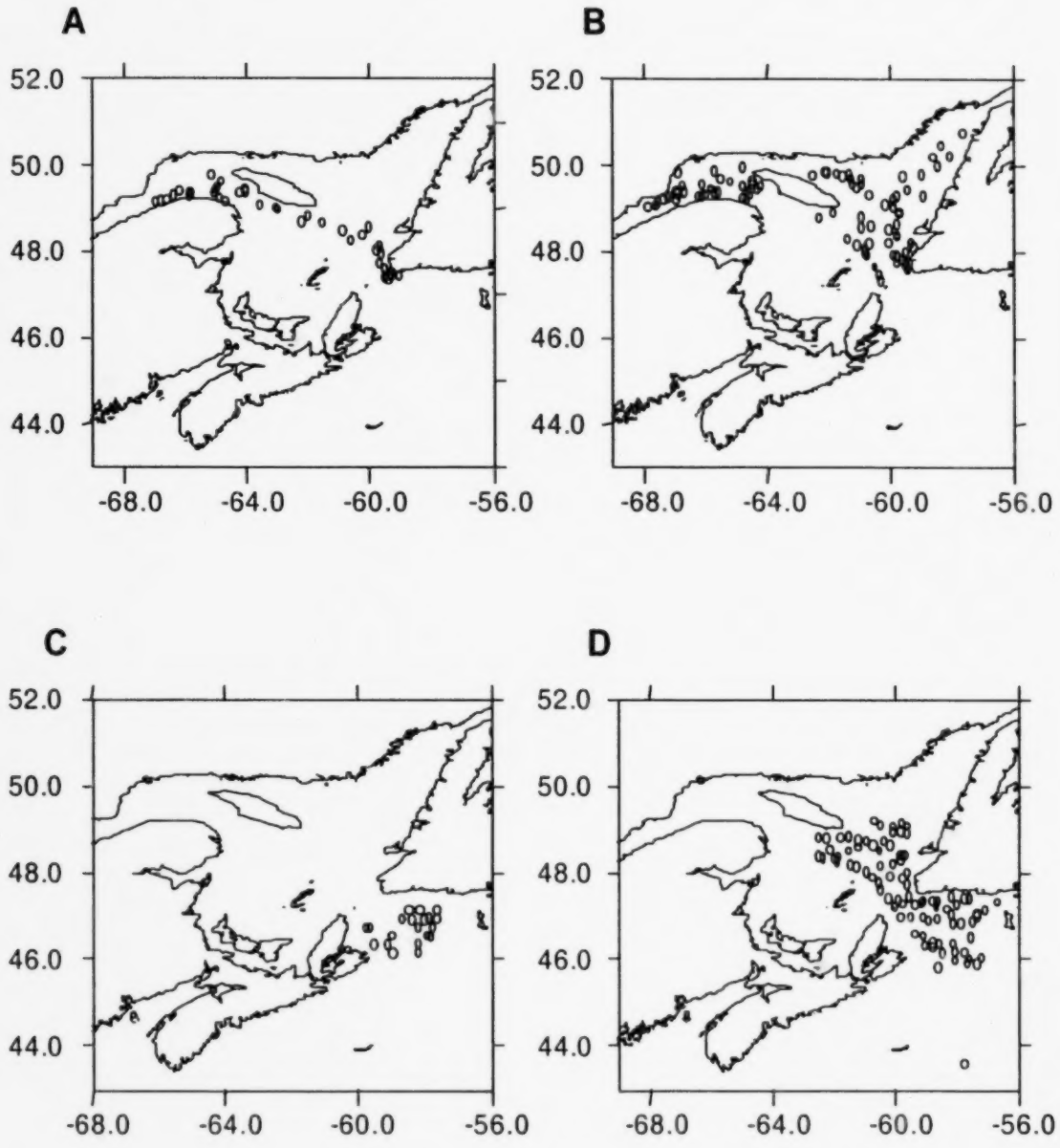


Figure 10.1. The areal coverage of the late-April 1997 (Teleost, A), August 1996 (Needler, B), January 1997 (Templeman, C), and November 1998 (Richmond Odyssey, D) research surveys in the Gulf of St. Lawrence and Cabot Strait area.

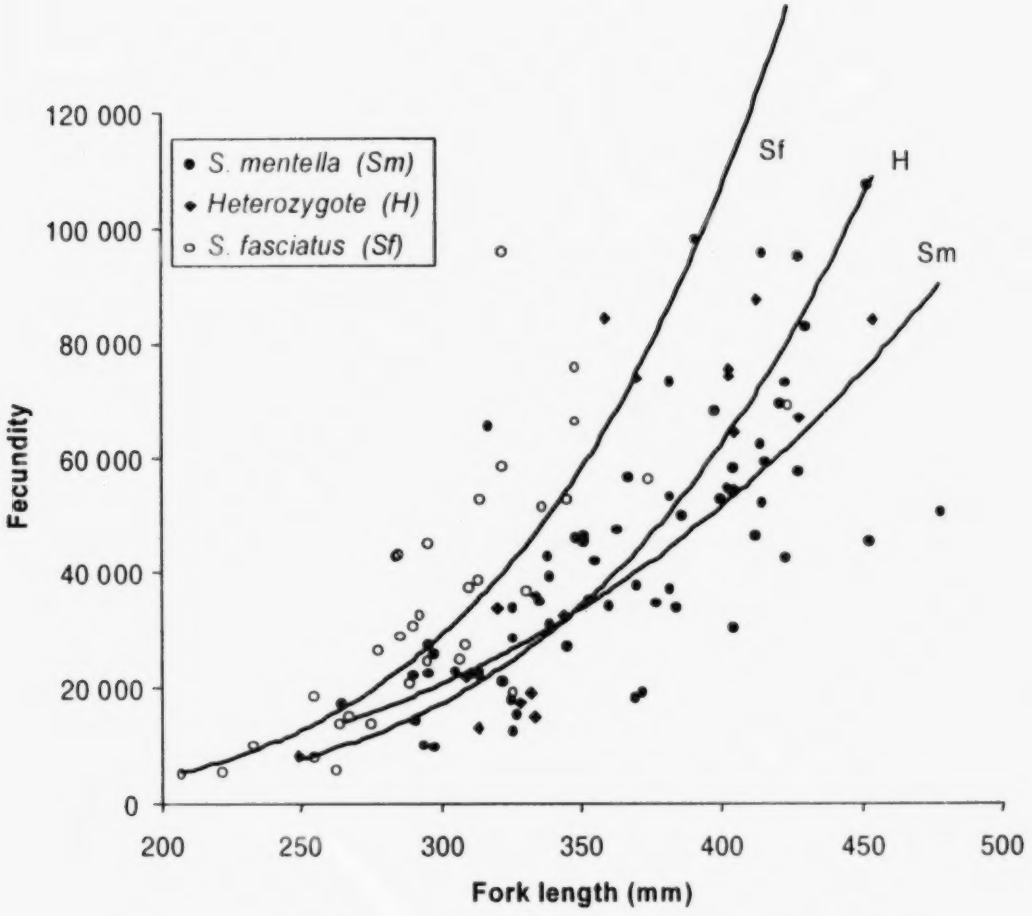


Figure 10.2. Relationship between fecundity and length for each species of redfish captured in NAFO area 3Pn4R in May 1997. Species were identified using the genotype at the MDH locus.

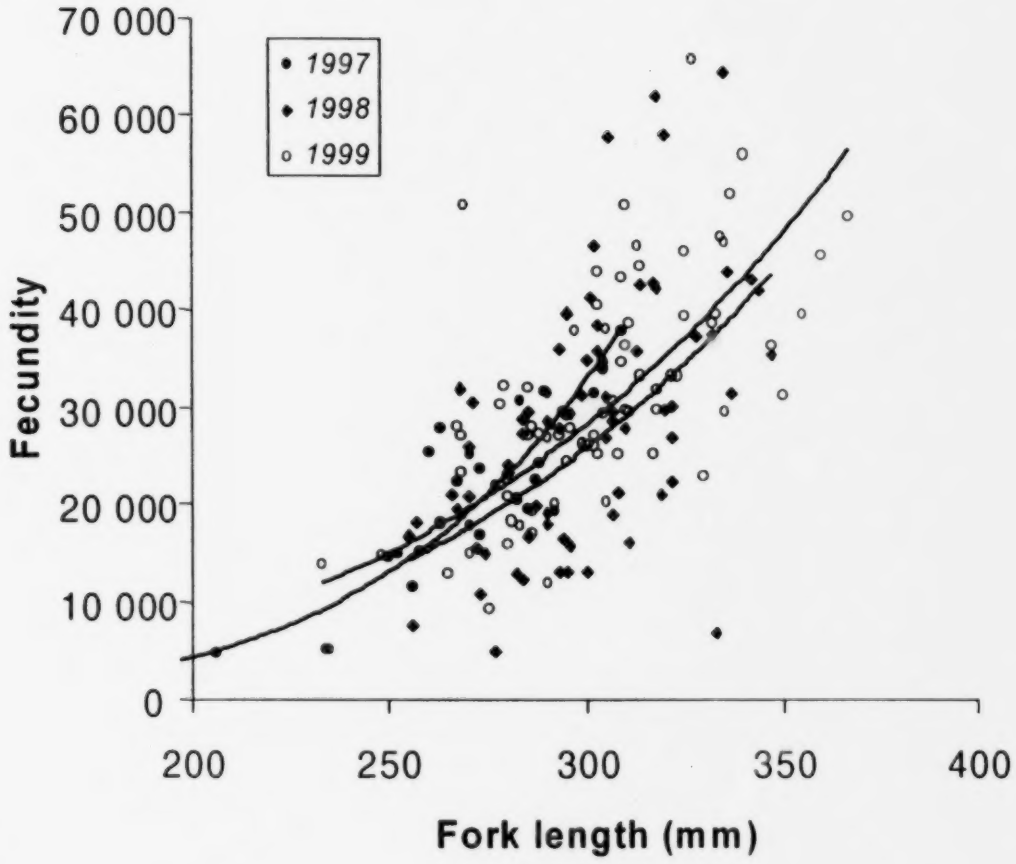


Figure 10.3. Relationship between fecundity and length for *S. fasciatus* (MDH*A2A2) captured in the St. Lawrence estuary (NAFO area 4T) in May 1997, 1998, and 1999.

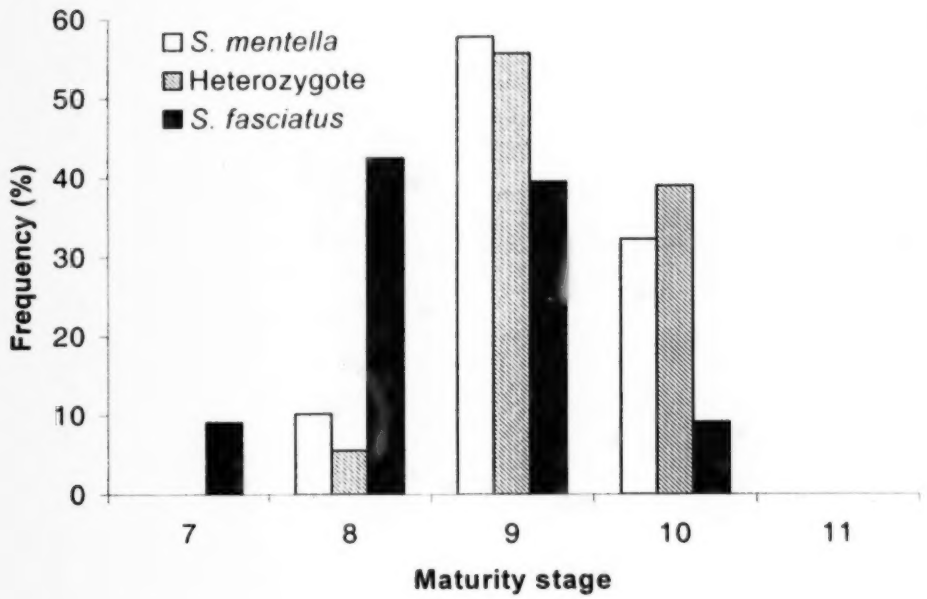


Figure 10.4. Maturity stage (St-Pierre and de Lafontaine 1985) of reproductive female redfish captured in the northern Gulf of St. Lawrence (3Pn4R) in April 1997. The proportion of females in the different maturity stages for each species are presented as percentages.

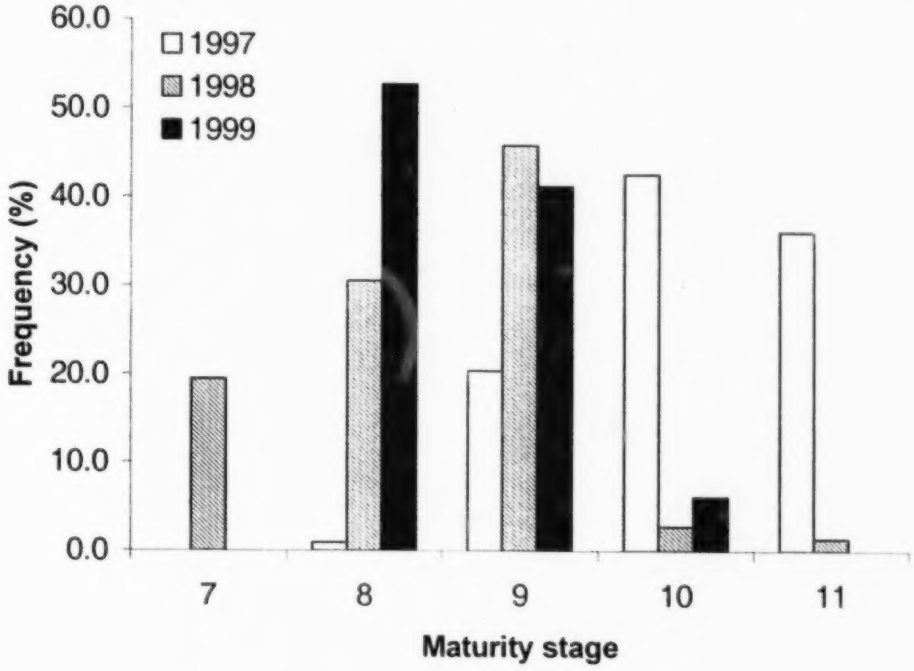


Figure 10.5. Maturity stage (St-Pierre and de Lafontaine 1985) of reproductive female *S. fasciatus* in the St. Lawrence estuary (4T) in May and early June 1997, 1998, and 1999. The proportion of females in the different maturity stages is presented as percentages.

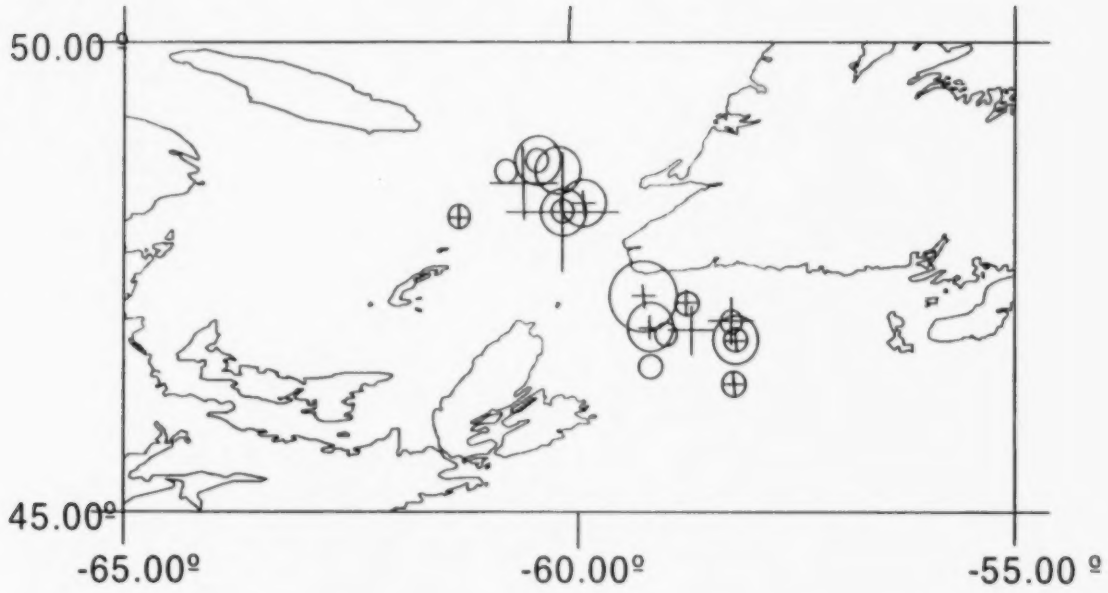
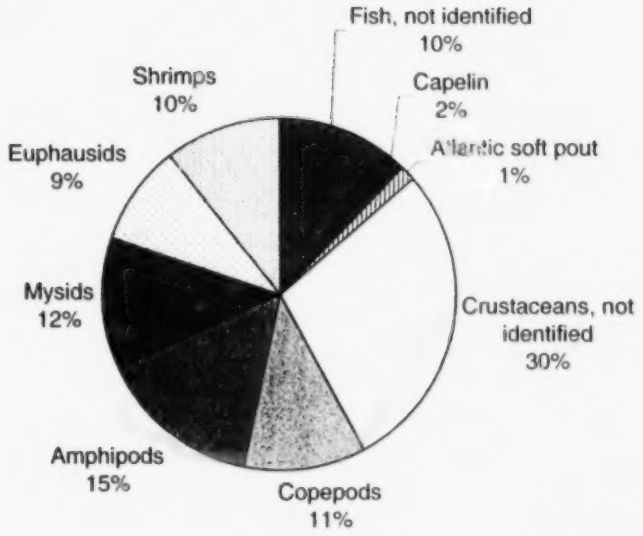


Figure 10.6. Mature female *S. mentella* and heterozygotes (MDH) with (+) and without (O) spermatozoa observed in the ovaries. Symbol size is proportional to the number of samples.

A) *S. mentella*



B) *S. fasciatus*

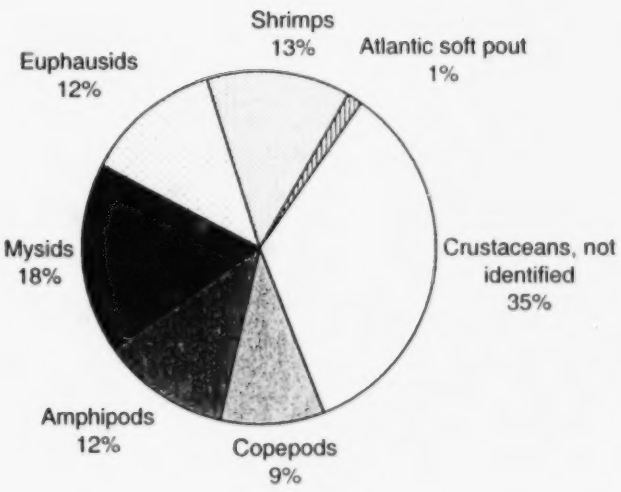


Figure 10.7. Proportion (%) of stomachs with different prey items in **A)** *S. mentella* and **B)** *S. fasciatus*.

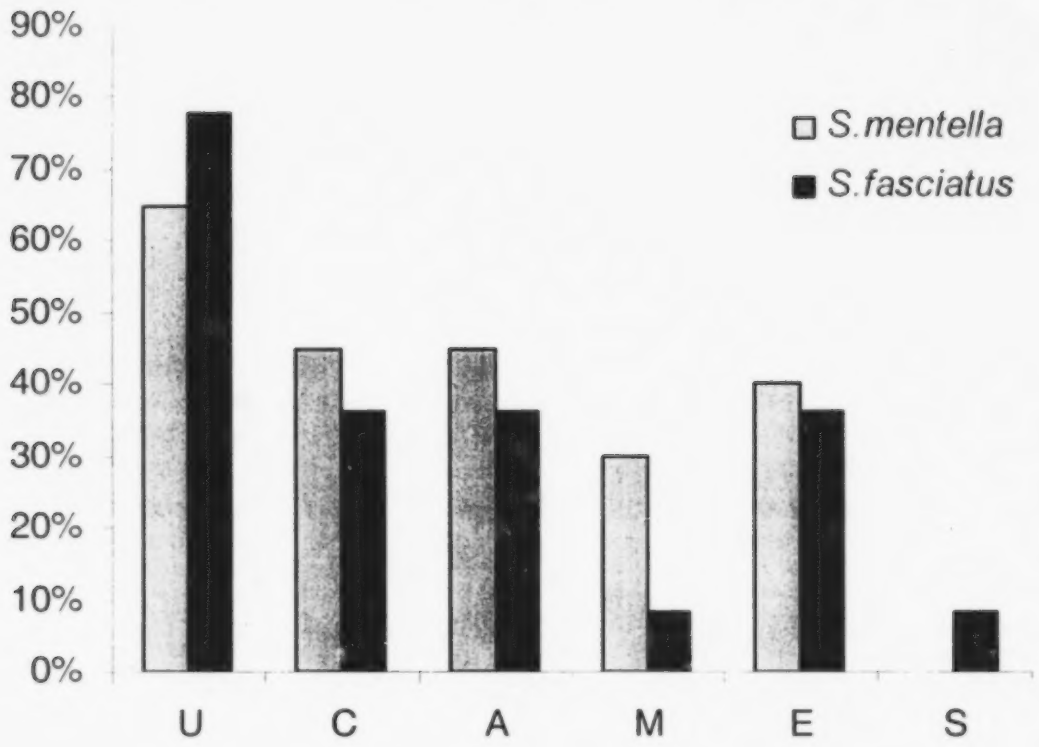


Figure 10.8. Proportion (%) of stomachs with different prey items in 147-299 mm *S. fasciatus* (n = 36) and *S. mentella* (n = 20). U, unidentified crustacean remains; C, copepods, A, amphipods, M, mysids, E, euphausids, S, shrimps.

11. The Use of Endogenous and Exogenous Resources During the Early Development of Atlantic Redfish (*Sebastes* spp.)

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Atlantic redfish (*Sebastes* spp.) are a commercially exploited groundfish in the NW Atlantic, yet little is known about the early life history of these species. Their ovoviviparous reproductive strategy and restriction to deep benthic environments during spawning makes studying embryogenic and larval stages difficult. Proper management of exploited fish species, however, depends upon a comprehensive understanding of early development as it is during the egg and larval stages that recruitment variability is considered to be largely determined. Two separate investigations described the use of endogenous and exogenous resources in larval redfish in an attempt to both provide insight into recruitment processes as well as understanding the evolutionary success of these species.

The first study examined changes in lipid and fatty acid profiles over five developmental stages of pre-extruded larvae (Table 11.1). During development within the female there was nearly a 50% reduction in total lipid, suggesting that lipids are an important source of energy and that metabolism of these resources occurs prior to parturition. Triacylglycerol was preferentially catabolised during embryogenesis over polar lipids unlike other Atlantic groundfish such as cod (*Gadus morhua*) and halibut (*Hippoglossus hippoglossus*) (Figure 11.1). High variability in these lipid reserves suggests that sensitivity to mismatches in prey after parturition likely varies between broods.

The second study investigated behaviour, growth and survival of larval redfish reared under prey abundances of 0, 500, 1 500 and 4 500 prey L^{-1} in laboratory conditions. A few larvae survived to day 18 in the 0 prey L^{-1} treatment despite possible handling stress from collection and transporting, but over 50% of the larvae in this treatment died by day 5. Growth, survival and condition of larvae varied with prey abundance but were highest in the 1 500 prey L^{-1} treatment. The significantly lower prey bite:orient ratios in the 4 500

prey L^{-1} treatment suggest that larvae may be distracted at higher prey abundances. A possible distraction effect may explain the significant reduction in growth and survival of larvae reared in the highest prey treatment. Although the prey abundances used in this experiment are higher than those reported in the field, comparisons with other rearing experiments suggest that prey availability may not be as limiting to redfish as for other commercially important species such as Atlantic cod.

In similar experiments on Atlantic cod we have found that cod survive, grow and forage better at prey abundances close to 3 times greater then was found for redfish (Table 11.2). Cod were also found to grow at a rate 3 times higher then redfish. This, taken together with the foraging behaviour data, suggest that redfish perform better at low prey abundances than cod. It is likely that cod larvae may outperform redfish larvae when prey levels are high in the field but the reverse is true at low prey levels. Another possible influence on larval redfish survival is predation by cod larvae. It is known that cod larvae become cannibalistic around 1 cm in length. Given the faster growth rate of cod relative to redfish larvae it may be that cod could prey upon the slower growing redfish larvae in years when prey abundance is high. Thus the co-occurrence of redfish and cod larvae and the dynamics of that co-occurrence may hold a key to the recruitment of redfish.

A recommendation arising from this study would be to eliminate or reduce fishing during the extrusion period of females. Given the development of larvae that takes place within the female, it is suggested that reducing stress during this period would increase the quality of extruded larvae. It is known that stress from fishing can reduce larval quality in cod and the same may be true for redfish.

Table 11.1. Description of developing pre-extruded redfish stages based on eye diameter, total length and pigmentation patterns.

Developmental Stage	Definition
D1	Larvae are unhatched (egg diameter ~1.6 mm) but eyes are clearly visible through the chorion.
D2	5.0-5.5 mm larvae with large yolk sacs. Eyes are 0.29-0.31 mm in diameter and no pigmentation is visible along the body.
D3	6.0-6.5 mm larvae with large yolk sacs. Eyes are larger than D2 larvae (0.38-0.42 mm) but pigmentation is still absent along the body.
D4	6.5-6.8 mm larvae with noticeably reduced yolk sacs from D2 and D3 stages. Pigmentation is present along the dorsolateral surface of the gut and melanophores are punctate in shape. Eyes are 0.5-0.51 mm in diameter.
D5	6.8-7.2 mm larvae with vestiges of yolk sacs remaining. Pigmentation is present along the dorsolateral surface of the gut as well as dorsally over the brain. Further pigmentation is seen along the dorso- and ventro-midlines. Melanophores are either stellate or branched in shape, often connected within postanal areas. Eyes are slightly larger (0.52-0.53 mm) than larvae in D4.

Table 11.2. Mean growth rate (MGR), survival and attack rates of Atlantic redfish (*Sebastes* spp.) and Atlantic cod (*Gadus morhua*) reared at low (1000-1500 prey L^{-1}) and high densities (4000-4500 prey L^{-1}).

SPECIES	VARIABLE	LOW PREY	HIGH PREY
Sebastes spp.	MGR (mm d^{-1}) †	0.074	0.059
	Survival (%) ††	22.3	8.0
	Attack Rate (prey min^{-1}) ††	2.8	0.5
Gadus morhua	MGR (mm d-1) †	0.129	0.186
	% Survival †	2.0	22.3
	Attack Rate (prey min-1) ††	1.9	3.2

† Data based on weeks 1-6 of the rearing period.

†† Data based on week 6 of the rearing period.

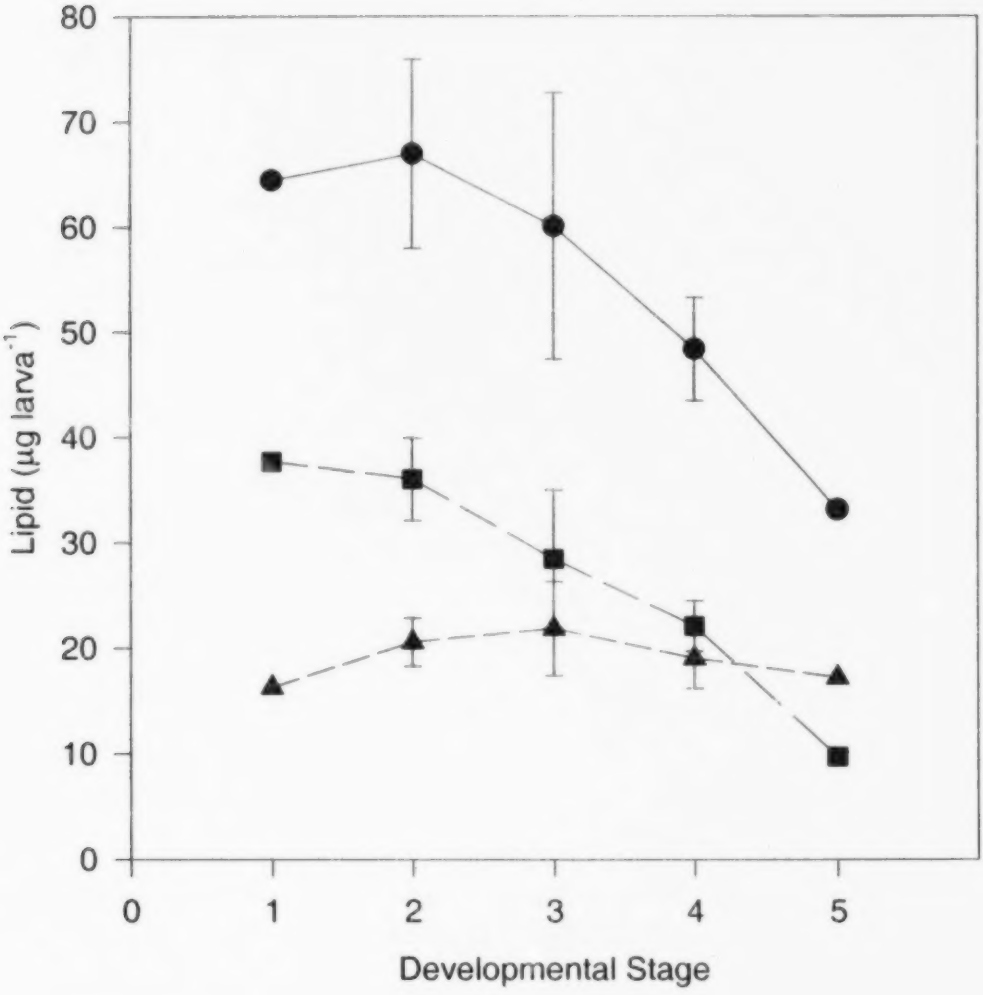

Figure 11.1. Changes in absolute amounts of total lipid (●), triacyglycerol (TAG; ■) and phospholipids (PL; ▲) throughout the development of pre-extruded redfish larvae. Data presented as mean (± 1 SE) of 1-5 samples of 10 pooled eggs or larvae.

VI. CONCLUDING REMARKS

12. Summary and main conclusions

The objectives of the program were ambitious in attempting to examine numerous aspects of redfish biology in the Northwest Atlantic. In its three-year duration, the program resolved many issues key to the management of these stocks and provided a wealth of new information on the biology of these species. It also raised, not unexpectedly, more questions than it provided answers, but the results established the foundation upon which more specific questions and hypotheses can be tested.

The major results of the programs are:

Species and stock ID:

- The genetics work using micro-satellites has clearly confirmed the separation of *S. mentella*, *S. fasciatus* and *S. marinus* as well as indicating the existence of introgressive hybridisation between *S. mentella* and *S. fasciatus* in Unit 1 and Unit 2. Genetics analyses have confirmed and clarified earlier results based on rDNA, MDH, gas bladder musculature and the number of soft rays in the anal fin.
- Results indicate sufficient mixing between Unit 1 and Unit 2 so as to make redfish in these areas genetically inseparable, although analyses of parasite fauna suggest that the migration rate between the two Units may be restricted.
- Results also indicate that redfish from the Unit 1-2 complex are a separate genetic population from those further South (Unit 3 and Gulf of Maine) and those North (Grand Banks and Labrador).
- Generally, the results provide preliminary information on stock structure in the whole Northwest Atlantic and suggest that the biological populations occupy perhaps much larger areas than the current management units.

Biology and Ecology

- Results have provided detailed information on the reproductive cycle, maturation, growth and fecundity of both *S. mentella* and *S. fasciatus* in Units 1 and 2 and has confirmed the differences between the species.
- The distribution of redfish has changed in Unit 1 during the 1990's (deeper and further South); however the temperature/depth preferences of redfish do not appear to explain these changes in distribution. These temperature/depth preferences are similar for Unit 1 and Unit 2 redfish, but different for Unit 3 redfish.
- In situ measurements have permitted to accurately measure the acoustic properties of redfish and advances in the use of acoustics as an enumeration tool were made.

The results raise important questions about the management of redfish stocks. The biological units that were identified in the genetic study do not correspond with the man-

agement units that are currently in use. No differences were found between Unit 1 and Unit 2 redfish, suggesting that they belong to a single "population" exhibiting several dynamic features characteristic of a metapopulation (several spawning locations and migration patterns, with extensive mixing during part of the year (i.e. winter).. In particular:

- Unit 1 and Unit 2 redfish appear to belong to a single stock complex. The spatial structure of the populations remains unclear and the appropriate management strategy for these fish needs to be investigated further.
- What are the migration and movement patterns of redfish in the Laurentian Channel area: are the fish freely moving between areas or are there fish restricted to specific areas; or is there a mix of migratory and sedentary fish?
- Is one area dependent on the other one for recruitment? Synchrony in recruitment is compatible with this hypothesis, but external events (i.e. environmental factors) may account for this observation. Is there larval transport or ulterior redistribution of recruits after settlement? Will depopulated areas in Units 1 or 2 be recolonised or not?
- Are both species behaving the same way over the Unit 1/Unit 2 area or are there site specific differences?

In other areas, the results available are not as detailed as they are for Units 1 and 2. However, questions arise pertaining to Unit 3 such as should the shelf edge, basins and Gulf of Maine be managed separately? Similarly, what are the appropriate management units on the Grand Banks and further north.

The Multidisciplinary Redfish Program has resulted in a wealth of invaluable new information about redfish in the Northwest Atlantic, but as with any good science it has resulted in the development of new hypotheses. We do have a much better understanding of the stock structure of redfish in the area, although it is far from clear how these broad units are internally structured and what happens at their boundaries. We also have a much better understanding of the environmental requirements of redfish. There is clearly much more work to be done: a current research program examines in depth the interactions between Unit 1 and Unit 2 to determine the relevance of these two units.

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ANNEXES

Annex I Publications resulting from the Program

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Annex II Chronology of the Redfish Program

Date	Event	Location
1994/12	Groundfish Management Plan: Redfish program announced	
1995/02/27- 1995/03/02	Redfish Workshop	Laboratoire Réné-Poirier (DFO/ CFIA) Longueuil (QC)
1995/06/02- 1995/06/02	Redfish workshop to discuss research priorities; 42 participants from Science, Fisheries management and Industry Chair Serge Labonté	Halifax (Holliday Inn)
1995/09/07	Steering committee meeting	Montréal (Château Champlain)
1995/09/28	Discussion paper for planning purposes	
1995/10/28	Project proposal submission	
1995/11/03	Steering committee meeting	Conference Call
1995/11/14- 1995/11/15	Planning Scientific Workshop	Institut-Maurice Lamontagne
1995/12/21	Program Proposal	
1996/01/23	Approval of Program by NSDC[1]	
1996/01/31- 1996/02/01	Scientific Committee Meeting	Halifax
1996/03/05- 1996/03/07	Redfish Sampling Strategies Workshop	BIO, Dartmouth
1996/05/08	Presentation of Program to Industry Workshop	Halifax (Holiday Inn)
1996/06/28	Annual Report	
1996/10/31	Progress Report	
1996/11/29	Steering Committee Meeting	Conference Call
1996/12/11	Annual Report	
1997/04/03	Scientific Committee Meeting (project Review)	Conference Call
1997/10/24	Steering Committee Meeting	Halifax
1997/10/31	Progress Report	
1999/03/31	End of Program	
1999/11/16-17	Industry Workshop: Presentation of the results to industry	Moncton

[1] National Sciences Director Committee.

Annex III Mandate, Steering Committee and Scientific Committee:

The objective of the MULTIDISCIPLINARY REDFISH PROGRAM is to examine aspects of the biology and fisheries of redfish to develop a better understanding of these species in order to insure long term economic viability and sustainability of the fishery.

STEERING COMMITTEE

Terms of reference:

The Steering Committee has the mandate, to supervise the Scientific Committee, in the design and implementation of a Multidisciplinary Research Program on the Northwest Atlantic redfishes mainly in, but not limited to, the areas of Unit 1, 2, and 3, and in NAFO Division 3O. The Steering Committee:

- Obtains the approval of the ADM Science and of Industry on the objectives and deliverable products for the Program.
- Approves the scientific proposals (objectives, hypotheses, project structure, etc.) prepared by the Scientific Committee.
- Approves budgets and financial plans for the Program as submitted by the Scientific Committee.
- Insures that proper scientific reviews of the research projects are performed.
- Assesses quarterly the Program's progress towards the established objectives and deadlines and makes the adjustments as required.
- Coordinates the presentation to clients of the results of the Research Program prepared by the Scientific Committee on a yearly basis.

Committee membership:

The Steering Committee is comprised of 5 scientists and 3 representatives from the redfish fishing industry. The chairman of the committee is the program manager from DFO.

Chairman:	Serge Labonté (DFO)
Scientists:	D. Gascon (DFO)
	D.B. Atkinson (DFO)
	R. Branton (DFO)
	P. Smith (DFO)
Industry:	Gabriel Gregory (FPI)
	Michael O'Connor (NSP)
	Robert Haché (APPA)
Secretary:	B. Morin (DFO)

Frequency of meetings:

The Steering Committee meets at least twice a year. On a *ad hoc* basis, conference calls or E-Mail correspondence are used.

SCIENTIFIC COMMITTEE

Terms of reference:

The Scientific Committee reports to the Steering Committee. The Scientific Committee is comprised of the main investigators of the Program and is established gradually as the Program is structured and research projects are incorporated. The initial development of the Program, and the formation of the Scientific Committee is illustrated in the attached flow chart.

The Scientific Committee has the mandate of supervising and coordinating the scientific operations of the Research Program. The Scientific Committee:

- Prepares the documentation (the proposal) defining the objectives, the hypotheses, the project structure, the protocols, and the deliverable products.
- Insure the day to day coordination of the Program (staff, material, vessel, etc.).
- Prepare an annual report describing the achievements during the year as well as any departures from the original planning.

Annex IV Final Workshop

Date: 16 and 17 November 1999
Department of Fisheries and Oceans
Gulf Fisheries Center, Moncton
Chairman: D. Gascon

Agenda

Tuesday 16 November

13:15 – 13:30 Introduction to the workshop. D. Gascon (Maurice-Lamontagne Institute, DFO)

Session 1: ***Species identification and characteristics and stock structure***

13:30 - 14:00 Redfish species identification and distribution based on various genetic markers and morphological variation. J.-M. Sévigny (Maurice-Lamontagne Institute, DFO), B. Branton (Bedford Institute of Oceanography, DFO), D. Power (Northwest Atlantic Fisheries Centre, DFO), B. Desrosiers (Institut des Sciences de la Mer), M. Black (Maurice-Lamontagne Institute, DFO) and É. Parent (Maurice-Lamontagne Institute, DFO).

14:00-14:30 Discrimination of redfish species and populations in the Northwest Atlantic using microsatellites. S. Roques, L. Bernatchez (Université Laval) and J.M. Sévigny (Maurice-Lamontagne Institute, DFO).

14:30-15:00 Application of the truss analysis method to the discrimination of *Sebastes fasciatus* and *Sebastes mentella* in the Gulf of St. Lawrence. A. Valentin, J.-P. Chanut (Institut des Sciences de la Mer) and J.-M. Sévigny (Maurice-Lamontagne Institute, DFO).

15:00-15:15 Coffee break

15:15-15:45 Growth and Maturity of Redfish *(Sebastes* sp.*)* in Mgt. Units 1,2,3 & NAFO Div 3O. R.M. Branton (Bedford Institute of Oceanography, DFO), B. Morin (Maurice-Lamontagne Institute, DFO), D. Power (Northwest Atlantic Fisheries Centre, DFO) and J.-M. Sévigny (Maurice-Lamontagne Institute, DFO).

15:45-16:15 Use of parasites in stock identification of the deepwater redfish (*Sebastes mentella*) in eastern Canada. D.J. Marcogliese (Centre Saint-Laurent, EC) and E. Albert (Maurice-Lamontagne Institute, DFO).

General discussion

Wednesday 17 November

Session 2 ***Distribution, migration and recruitment studies***

09:00-09:30 Inferences on redfish migrations through an analysis of commercial logbook information for Management Units 1-3 from 1985-1992. D. Power (Northwest Atlantic Fisheries Centre, DFO).

09:30-10:00 Distribution changes of redfish in the Gulf of St. Lawrence based on research surveys data M. Castonguay and B. Morin (Maurice-Lamontagne Institute, DFO).

10:00-10:30 Temperature exposure history for redfish. P. Smith (Bedford Institute of Oceanography, DFO).

10:30-10:45 Coffee break

10:45-11:15 Identification and distribution of the larvae of redfish species (*Sebastes fasciatus* and *S. mentella*: Scorpaenidae) in the Gulf of St. Lawrence J.-M. Sévigny (Maurice-Lamontagne Institute, DFO), P. Gagné (Université Laval), Y. de Lafontaine (Centre Saint-Laurent, EC) and J. Dodson (Université Laval).

11:15-11:45 The use of endogenous and exogenous resources during the early development of Atlantic redfish (*Sebastes* spp.). J. Brown and B. Laurel (Ocean Science Center, Memorial University of Newfoundland).

11:45-12:15 Review of the possible causes for the disappearance of the 1988 year-class in the redfish population of the Gulf of St. Lawrence. B. Morin, S. Hurtubise, M. Hammill and D. Gilbert (Maurice-Lamontagne Institute, DFO)

12:15-14:00 Lunch break

13:30-14:00 Advancement of acoustic survey design for redfish S. Gauthier and G. Rose (Memorial University of Newfoundland).

Discussion, report and concluding remark.

Participants

Atkinson, Bruce	Northwest Atlantic Fisheries Centre, DFO-Newfoundland
Bollivar, David	SeaFreez Foods Inc.
Branton, Robert	Bedford Institute of Oceanography, DFO-Maritimes
Brown, Joe	Memorial University -Ocean Science Centre, Newfoundland
Camiran, Réjeanne	Maurice Lamontagne Institute, DFO-Quebec
Chapman, Bruce	Fisheries Resources Conservation Council (FRCC)
Gascon, Dominique	Maurice Lamontagne Institute, DFO-Quebec
Gaudet, Mario	Department of Fisheries and Aquaculture, New Brunswick
Gauthier, Stéphane	Memorial University, Newfoundland
Gauvin, Alyre	A.P.P.F.A.
Gillis, Dave	Fisheries and Tourism, Prince Edward Island
Halliday, Ralph	Bedford Institute of Oceanography, DFO-Maritimes
Hennessey, Frank	Fisheries Resources Conservation Council (FRCC)
MacRinnon, Clarie	Department of Fisheries, Nova Scotia Department of Fisheries and Aquaculture
Lemelin, Dario	Ministère de l'Agriculture, des Pêcheries et de l'Alimentation du Québec
Morin, Bernard	Maurice Lamontagne Institute, DFO-Quebec
O'Connor, Michael	National Sea Products
Power, Don	Northwest Atlantic Fisheries Centre (DFO-Newfoundland)
Roques, Séverine	Université Laval
Sévigny, Jean-Marie	Maurice Lamontagne Institute, DFO-Quebec
Valentin, Alexandra	Institut des Sciences de la Mer (UQAR)
Yeadon, Maureen	Fisheries Resources Conservation Council (FRCC)